MACHINE TOOL TESTS AND ALIGNMENTS.

Paper presented to the Institution, London Section, by Dr. Georg Schlesinger.

IT is not intended to restrict this lecture to the inspection of machine tools by alignment tests. Attention will be given mainly to the workshop conditions which led to the publication of the "Inspection Book."*

In order to deal with the most important aspects of the subject in the short time available, consideration will be confined to drilling machines, lathes and milling machines.

Power and Precision of Machine Tools.

All tests and alignments of machine tools are based upon two considerations :—

(1) Every machine tool must be strong enough to utilize the full power of its driving motor when cutting any given material under the coarsest condition of feed. This may be called the *power* of the machine.

(2) Every machine tool must be made sufficiently accurate to produce interchangeable work within the usual limits. The alignments of the machine are intended to safeguard this accuracy which may be called the *precision* of the machine.

The power and precision of a machine allow one to form an opinion as to the degree of accuracy which one may expect in work produced on the machine under ordinary conditions of service. In forming such an opinion, however, one has to realise :—

(*a*) In roughing out work, the surface does not require to be either accurate or well finished. For such purposes one ought to buy suitable roughing machines and it is not for such machines that the tests and alignments of the Inspection Book are intended.

(*b*) On the other hand, for the highest precision, one should definitely use a fine finishing type of machine, e.g., fine boring or honing machine, grinding machine or even the diamond tool lathe.

If heavy roughing work is carried out even once on a fine finishing machine such as in Fig. 1, the column may become permanently deformed and the machine may be rendered unserviceable for precision work.

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*G. Schlesinger : Inspection Tests on Machine Tools. Mach. Pubg.Co., London.

The finest working limit is about 0.0001 in., and production to this accuracy necessitates that the temperature of the workshop should be kept at 20°C., the machine tool should have a good foundation, every source of vibration should be eliminated, and the set up of the machine should be checked every week.

Ball and roller bearings are made to an accuracy of 0.0001 in. and this accuracy prevails to-day in the construction of machine tools. Every workshop should, therefore, have available machine tools, such as, for example, fine boring machines, Fig. 1, with which such accuracy can be attained. Such machines are superior in accuracy to the ordinary high class machine tool and for that reason only one instance is dealt with in the inspection book under tool-makers lathes.

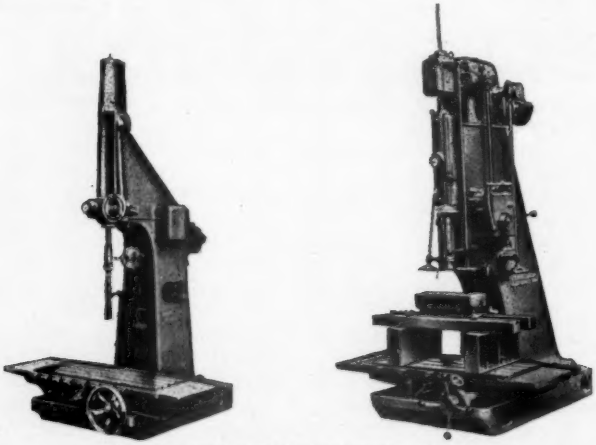


Fig. 1.—Superfine Boring and Honing Machines.

One should not be misled by the fineness of the graduations on the dials of some measuring instruments. Their dimensions are sometimes made to represent 0.001 mm. (0.00004 in.) but the actual accuracy is seldom higher than 0.005 mm. (0.0002 in.).

We will concern ourselves this evening with standard commercial machine tools having (1) sufficient power for roughing and finishing, and (2) sufficient accuracy for manufacturing interchangeable parts to I.S.A.* limits.

Great Britain does not actually belong to the I.S.A. but, so far as I know, similar limits are worked to in good machine tool factories in your country.

* International Federation of Standardisation Associations.

All the power tests of machine tools are based upon the very simple formula :—

$$N=C.P.v$$

in which N=horse power of motor,
P=force required to remove a certain size of chip,
v=cutting speed per min.
C=known constant factor.

For example,

If P=1200 kg.=2650 lb.
v=10 m/min.=32.8 ft./min.

Then $$N=\frac{1200\times 10}{75\times 60}=2.67 \text{ h.p.}$$

Similarly, if P=120 kg.=265 lb.
v=100 m/min.=328 ft./min.

Then, once again $$N=\frac{120\times 100}{75\times 60}=2.67 \text{ h.p.}$$

These simple examples illustrate the peculiarity of the machine tool as regards power. If a machine tool is used for roughing hard steel by removing a chip of 6 sq. mm. section, the force required is 1200 kg. at a cutting speed of 10 m/min. If the same machine is used on brass with a tool pressure of 120 kg., the cutting speed can be increased to 100 m/min. The h.p. expended would be 2.67 in each case. Instead of the light cut on brass, the machine could be used for finishing cuts on hard steel, in which case the cutting speed could be raised to something of the order of 100 m/min. if desired.

Drilling Machines.

Let us now turn to the examples of machine tools mentioned earlier and consider first the radial drilling machine, Fig. 2. In

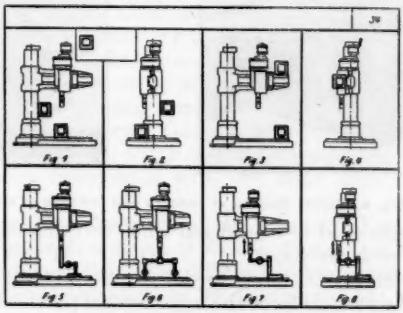


Fig. 2.—Tests on Radial Drill.

this machine, one of the points usually specified is the maximum permissible deflection of the arm when the largest size drill is being used with the saddle at the outermost position. The appropriate rates of feeds for different sizes of drills are given on p. 16 of the Inspection Book. The resulting end-pressures are also stated.

In the case of a well ground 2 in. drill, for example, the rate of feed is 0.018 in. and the pressure 4070 lb. This example shows how important it is during alignment tests to appreciate the magni-

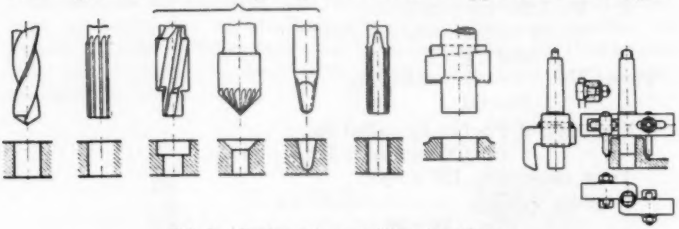


Fig. 3.—Tools used on Drilling Machines.

tudes of the forces which are likely to be applied to the member of a machine tool when in actual use.

The errors which can be allowed on the alignments can only be determined in relation to the power of the machine and with a proper knowledge of the forces and the resulting deflections which occur when the machine is in operation. The starting point for all considerations of alignments is the cutting tool itself.

In a drilling machine, one uses twist drills, reamers, counterboring and facing tools and taps, Fig. 3. Of these, twist drills set up the greatest forces when drilling in solid metal and for that

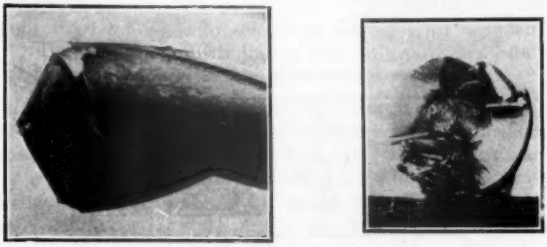


Fig. 4.—Drills blunted at corners and towards centre.

reason only drills need be considered when carrying out any acceptance tests on such machines.

The torque on a drill tends to destroy the cutting edges at the corners, and the vertical force the more central portion of the cutting edges, Fig. 4.

As the column of a drilling machine is usually made of ample strength to resist the vertical thrust due to the feed, the effect of the twisting moment on it is negligibly small. Thus the tests given in the inspection book are sufficient as regards the alignments

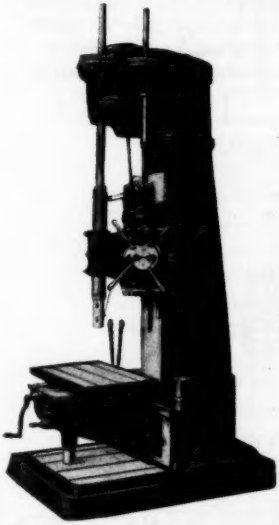


Fig. 5.—Rigid Column Drilling Machine.

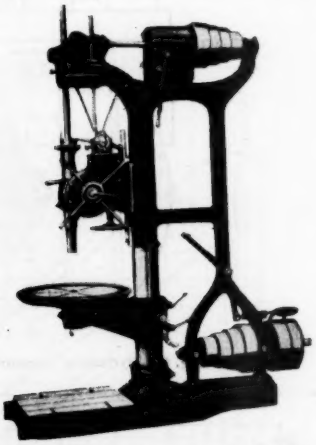


Fig. 6.—Light Frame Drilling Machine.

of these machines. It will be noted that separate test sheets are given for the radial machine, the rigid column machine, Fig. 5, and the light column machine, Fig. 6.

Experiments on Drills.

In order to investigate the forces which arise when drilling a hole, I built in my former laboratory in Berlin-Charlottenburg, a special measuring table, Fig. 7, for use on a drilling machine, which enabled measurements to be made of the direct thrust and the turning moment. Such a measuring appliance can also be made to serve a useful purpose in industry. One use to which this table was put was to determine the best shape of drill for deep holes in magnesium alloys: ordinary twist drills with the helix angle of 12° broke repeatedly.

The tests revealed the cause of the breakage, Fig. 8. A 5 mm. (0.2 in.) drill broke at a depth of 25 mm. (1 in.) as it was unable to withstand the thrust of 100 kg. (220 lb.) and a torque of 28 kg. cm. After altering the helix angle to 36°, the thrust fell to 28 kg. at a

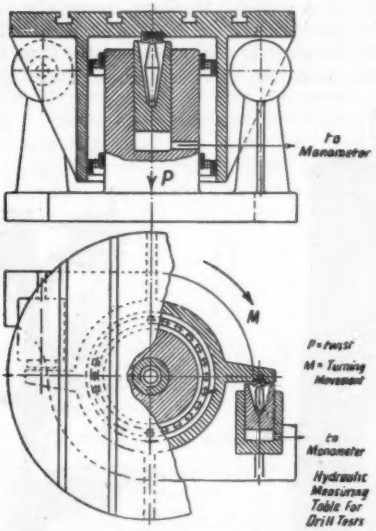
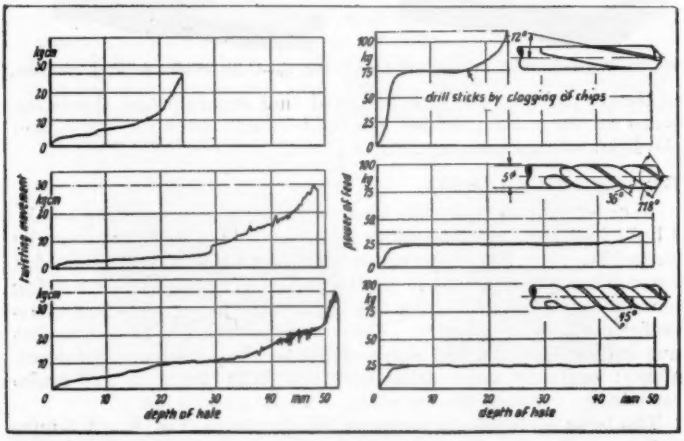


Fig. 7.—Hydraulic Measuring Table for Drilling Machine.



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Drilling tests in Electron [Magnesium-Alloy]

Fig. 8.—Drilling Tests in "Electron" (Magnesium Alloy).

depth of 50 mm. (2 in.), and the torque of 32 kg.cm. was not so great as to break the drill. A further change in the helix angle to 45° reduced the thrust to 25 kg. and the torque was about 35 kg.cm. at a 2 in. depth. In the case of the 36° and 45° angle drills the chips came away quite freely and the clogging action which was the cause of the 12° drill failing was entirely eliminated.

From such an investigation one obtains not only the best form of tool for a particular purpose, but at the same time the load on

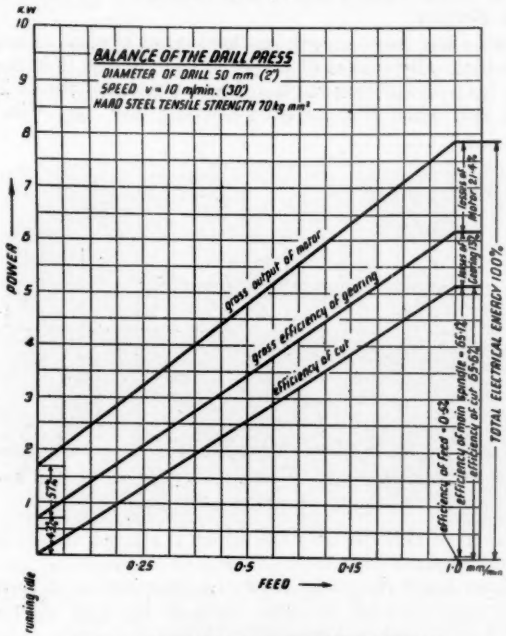


Fig. 9.—Power Diagram for Drilling Machine.

the machine is reduced to a minimum and likewise the power required. This all leads to higher accuracy.

The proof of the pudding is in the eating! In this case the eating refers to the number of deep holes which could be drilled with one drill. By paying attention to the shape and keenness of the tool one can preserve a machine and get the best out of it.

Efficiency of Cutting.

Fig. 9 shows the manner in which the electric power put into a drilling machine is expended. The diagrams relate to a 2 in. drill

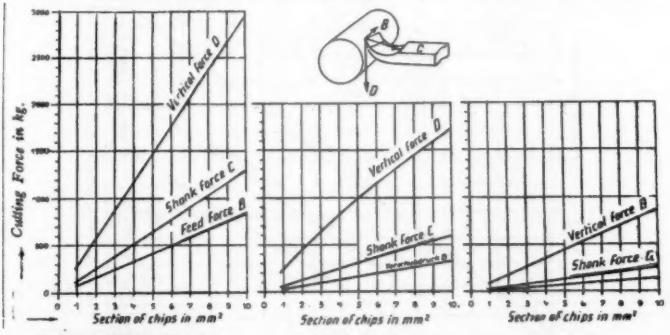
working in hard steel at a speed of 30 ft./min. The energy available for the actual cutting is obtained by subtracting the motor and gearing losses from the input. This energy is expended in applying the torque and feed to the main spindle.

It may not be generally known that of the total power consumption of a drilling machine, only 0.5% is expended in the feed and 65% in driving the spindle. The remainder is lost.

LATHES.

Cutting Forces.

The lathe has been chosen as the second typical example of a machine tool. By means of a special tool holder, it is possible to measure by hydraulic means the three component forces B, C, and D, on a tool when it is actually cutting, Fig. 10. The vertical



Chrome Nickel Steel. **Mild Steel.** **Cast Iron.**

Fig. 10.—Forces on a Lathe Tool.

tangential force D is the only one which is related to the power of the driving motor.

The three lower diagrams show the magnitudes of these forces when cutting chips of different cross sections in chrome-nickel steel, mild steel, and cast iron respectively.

For the same, cross section of chip of 10 sq.mm., the tangential force D is 2,950 kg. (6,500 lb.) for chrome-nickel steel, 1,700 kg. (3,800 lb.) for mild steel and 850 kg. (1,900 lb.) for cast iron.

Distortion of Bed.

As regards the distortion of the bed under the pressure of the cut, the feed-force B is of little account as it is relatively small and acts horizontally parallel to the length of the bed. On the other hand, the force C along the tool tends to twist the bed and the vertical force D to deflect it. As the deflection of the bed due to the twisting

effect of the force C is usually about 60 to 80% of the whole deflection, turning-tools should be ground so as to reduce this force to a minimum.

Calculations of the deflections of a lathe bed under the cutting forces are hardly possible on account of its complicated and varying section and the variation in the loading due to the movement of the saddle. The degree of solidity of the bearing of its feet upon the floor also plays an important part in the distortion which the bed undergoes in practice.

A few years ago, a research* extending over two years was carried out on the deflections of the bed of a lathe due to the cutting forces. The lathe used had a centre height of 250 mm. (10 in.) and in it was mounted a steel bar 1,620 mm. (5 ft. 4 in.) long, and 168 mm.

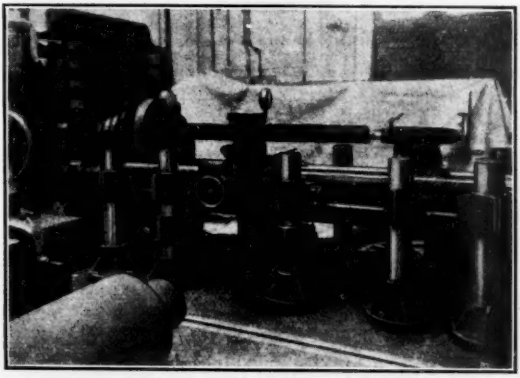


Fig. 11.—Apparatus for measuring Deformation of Lathe Bed.

(6½ in.) diameter. The forces on the cutting tool were D=1,200 kg. (2,650 lb.), C=433 kg. (950 lb.), and B=180 kg. (400 lb.). The deformation of the bed was measured with a number of dial gauges placed at several positions along its length (Fig. 11). It was found that the bed deflected most at the tailstock. Very little distortion occurred at the headstock end even with the heavy roughing cut used.

The deviations from a straight line of the axis of the work opposite the tool and the path of the tool itself are shown in diagram (b) of Fig. 12 for four positions S, T, U, and V. These deviations resulted in a lack of parallelism of the work as shown in diagram (c), the diameter being largest at the tailstock end by about 700μ (0.028 in.).

* Kickebusch–Werkzeugmaschine unter Last. V.D.I–Verlag, 1933–No. 360

The results of a second, preliminary finishing cut are shown in the upper curve of diagram (d). The forces D and C were then 250 kg. and 90 kg. respectively. Under this lighter cut the bar was much nearer parallel, the deviations being 50μ (0.002 in.) in the centre, 33μ (0.0013 in.) at the tailstock, and 20μ (0.0008 in.) near the headstock. A second fine finishing cut with D=40 kg.

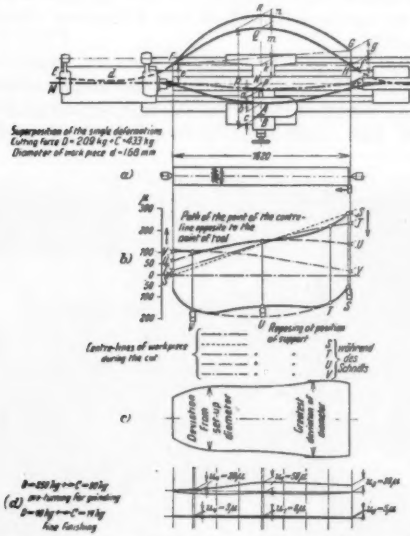

Superposition of the single deformations
Cutting force D = 209 kg + C = 433 kg
Diameter of work piece d = 166 mm
1520
a)
b)
Path of the point of the centre-line opposite to the point of tool
Centre-lines of workpiece during the cut
Position of supports
Deviation from set-up diameter
Greatest deviation of diameter
c)
(d)

Fig. 12.—Effect of Cutting Pressure on Lathe Bed and Parallelism of Work.

and C=14 kg. gave the result shown in the lower curve. This resulted in the bar being parallel to within 8μ (0.0003 in.), about six times the precision of the first finishing cut.

This lathe, therefore, combined power for roughing with precision for finishing. It was found, however, that after being used for twelve months, permanent deformations had taken place in the bed due to the heavy forces arising from roughing cuts, and the machine had to be completely overhauled before it could be used again for accurate finishing.

With data obtained in this manner it is possible to give definite figures in the Inspection Book for the permissible errors in the various alignments. Actually, the figures given in the Inspection Book for a lathe of this type were known empirically even thirty years ago and were being worked to by Loewe Gesfürel, Berlin, where a high grade of accuracy was demanded even in those days.

Later on, the knowledge that the twisting strain was mainly responsible for the deformation of the bed caused us to replace the straight vertical ribs by a zigzag arrangement, Fig. 13. By this means we obtained a bed which was much better able to resist twisting without increasing its weight.

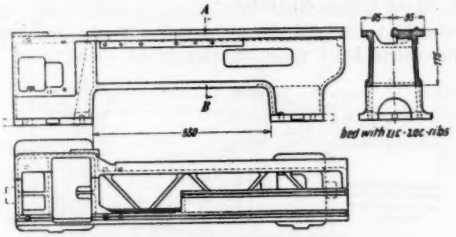


Fig. 13.—Rigid Lathe Bed with Cross Ribs.

The same principle has also been applied with equal success to boring mills, radial drilling machines, etc. It also forms the basis of the construction of machine tool members constructed from steel

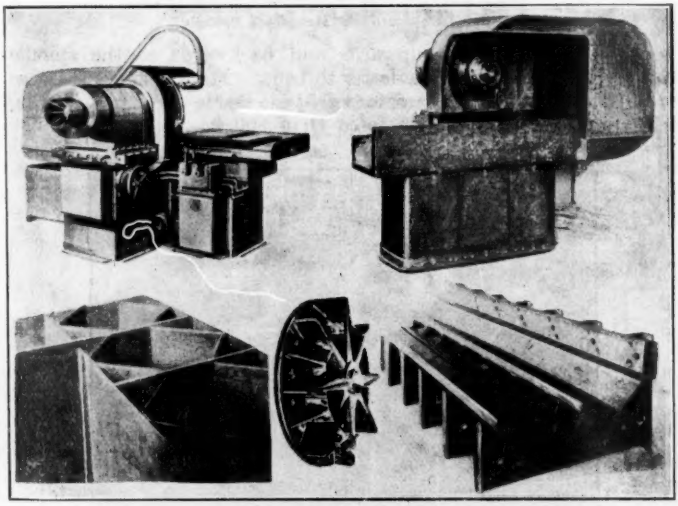


Fig. 14.—Fabricated Structures.

plates welded together in the form of trangulated cells, Fig. 14. Satisfactory stiffness can be obtained by using plates only 3 to 5 mm. thick.

In the so-called multi-tool machines, the forces and deflections must increase with the number of tools employed. The beds of these machines, which have motors of 20 to 40 h.p., must, therefore, be correspondingly stiff to resist the strains.

Distortion of Driving Spindle.

Besides the bed, the spindle of a lathe is also subject to severe strain. The main load falls on the front bearing of the spindle

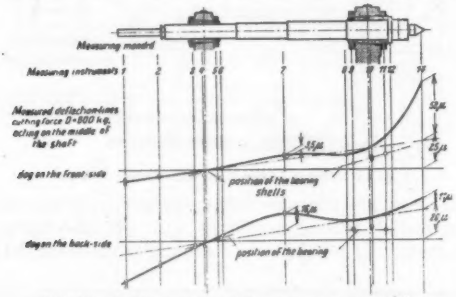

Measuring mandrel
Measuring instruments
Measured deflections cutting force D=800 kg. acting on the middle of the shaft
dog on the front side
position of the bearing shells
dog on the back side
position of the bearing

Fig. 15.—Deformation of Headstock Spindle.

which is strained both upwards and backwards as the spindle rotates and thus causes the latter to bend. Fig. 15 shows the case of a spindle having a diameter of $3\frac{1}{2}$ in. inside the front bearing when used under a cutting force D of 800 kg. (1,750 lb.). The

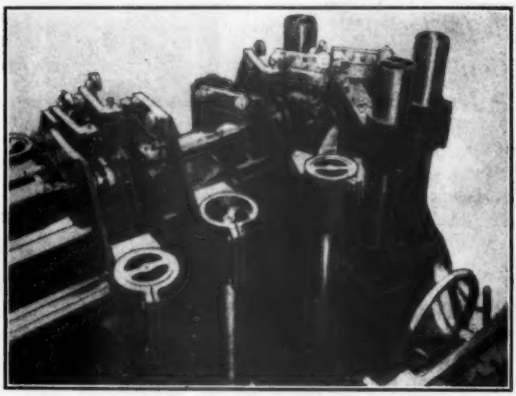


Fig. 16.—Testing Apparatus for Headstock Spindle.

deflections of this spindle were observed by means of 12 dial gauges (Fig. 16). The centre point was found to be deflected upwards by 78μ (0.003 in.) but there was very little disturbance at the back bearings. The front bearing has, therefore, to receive the most consideration in designing.

In present day designs of spindles one endeavours to avoid all unnecessary pressures on the spindle by fitting it with one gear wheel as near as possible to the front bearing, Fig. 17. The spindle is thus

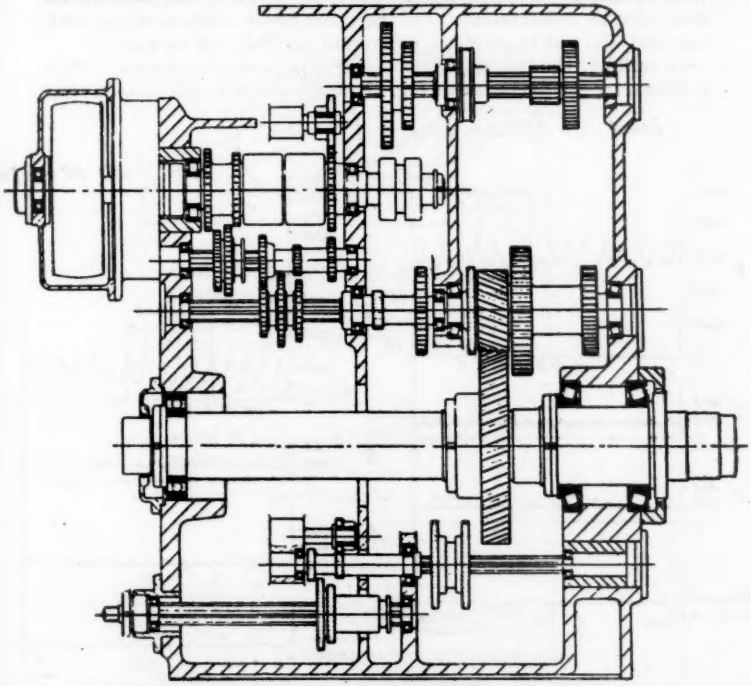


Fig. 17.—Lathe Headstock with single Driving Gear on Main Spindle.

subject to only one torque and one bending moment working at a constant leverage with respect to the bearings.

Ordinary cylindrical spindle bearings will stand the heavy pressures which arise in rough turning, but they are hardly suitable for the high speeds used in finishing. For the latter, roller bearings are more serviceable. They will not only stand heavy pressures but also permit the oil film to be adjusted between 0.01 and 0.02 mm. (0.0004 in. and 0.0008 in.).

MILLING MACHINES.

Cutters.

The third example is the milling machine. The peculiarity associated with this machine is that out of the several cutting edges of a milling cutter, only a few actually cut. In the case of a twist drill, on the other hand, both lips always cut together. With a milling cutter, the cutting action of any tooth is not uniform. When a cutter is working against the feed, the cut of the teeth varies from zero to a maximum. On the other hand, when working with the feed, the cut begins at a maximum and falls off to zero.

In milling, the cutting action is of a pulsating character. This is shown by the diagrams in Fig. 18, from which it will be seen that

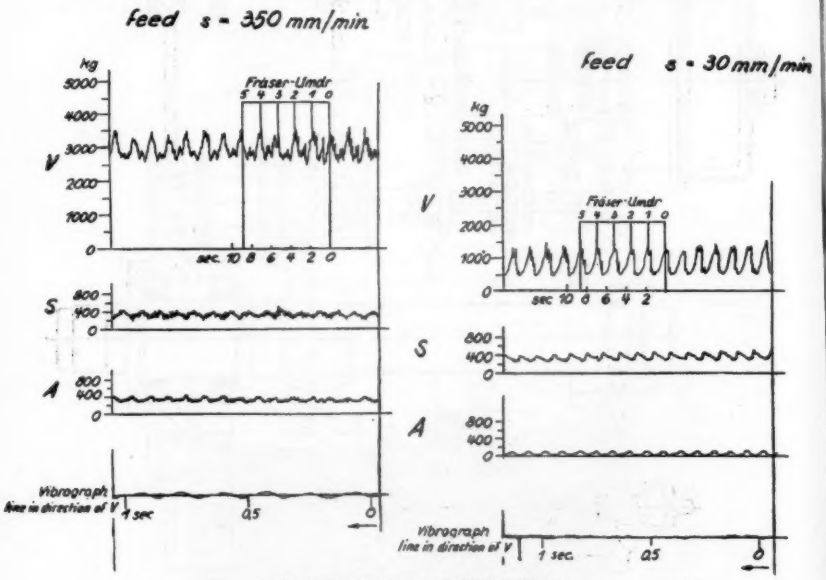
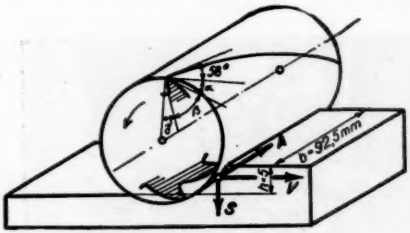


Fig. 18.—Diagrams of Milling Tests.

the principal pulsations occur at each turn of the cutter whether the feed be as much as 14 in. or as small as $1\frac{1}{4}$ in. per minute. The diagrams marked V, S, and A, relate to the horizontal force in the direction of the feed, the vertical force and the axial force respectively, as indicated in Fig. 19. The bottom diagrams in Fig. 18 were obtained from a vibrograph placed on the machine. As would be expected, the vibration was noticeably smaller at the slower feed.

This pulsating action of a milling cutter does not occur in the case of a tool in a lathe where the cutting is continuous and the cutting forces remain steady.

V = Feed-force (horizontal)
S = vertical force
A = axial force



Diameter of milling cutter D=120 mm = 4¾"
Number of teeth Z=10
Twist (helix) 58°
Cutting angles γ=27°45' β=57°15' δ=5°

number of revolutions
depth of cut h=5mm. = 0·2"
width of cut b= 92·5 mm = 3·5"
material, mild steel

Fig. 19.—Diagram and Dimensions of Milling Cutter.

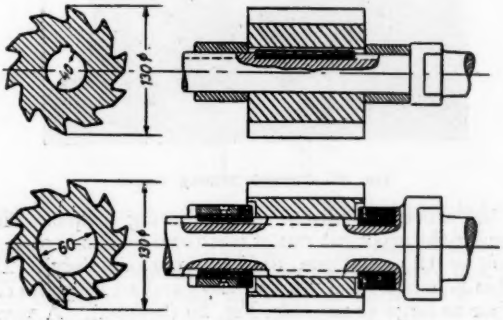
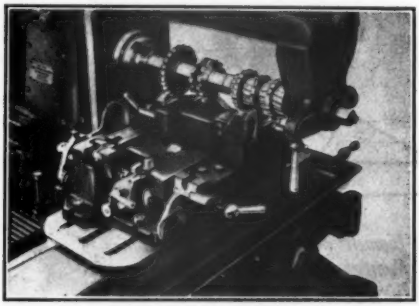


Fig. 20.—Methods of fastening Milling Cutters.

Arbors.

The weakest member of the milling machine is the milling-arbor. Ordinarily the cutter is driven by means of a single key, Fig. 20 (top), and any end-wise movement is prevented by a retaining nut. Sometimes the key is omitted and the drive is obtained merely by friction by tightening the nut very hard. Both methods are bad. A single driving key along one side gives rise to a one-sided bending



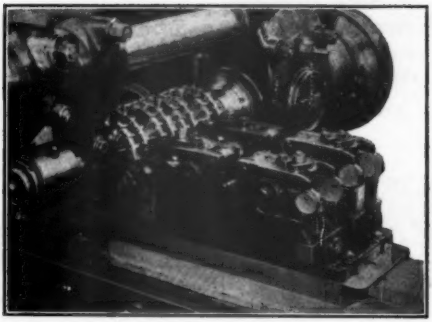


Fig. 21.—Multiple Milling Cutters.

force on the arbor in addition to the driving torque. This force tends to make the arbor run out of truth and results in eccentricities of as much as 0.2 or 0.3 mm. (0.01 in. approximately). To avoid this trouble it is better to use two keys and to keep the diameter of the arbor as large as possible, Fig. 20 (bottom). A comparison of the resistance of the two arbors shown in this figure shows that the

second arrangement with a 60 mm. (2.4 in.) arbor with two driving keys at each end of the cutter is more than twice as stiff as the 40 mm. (1.6 in.) one with a single key running through the cutter.

The tolerances stated in the inspection book relate to arbors of ample stiffness with the cutters driven in the proper manner. Fig. 21 shows arrangements of as many as eight cutters on a single arbor, some of the cutters being quite large in diameter. Such

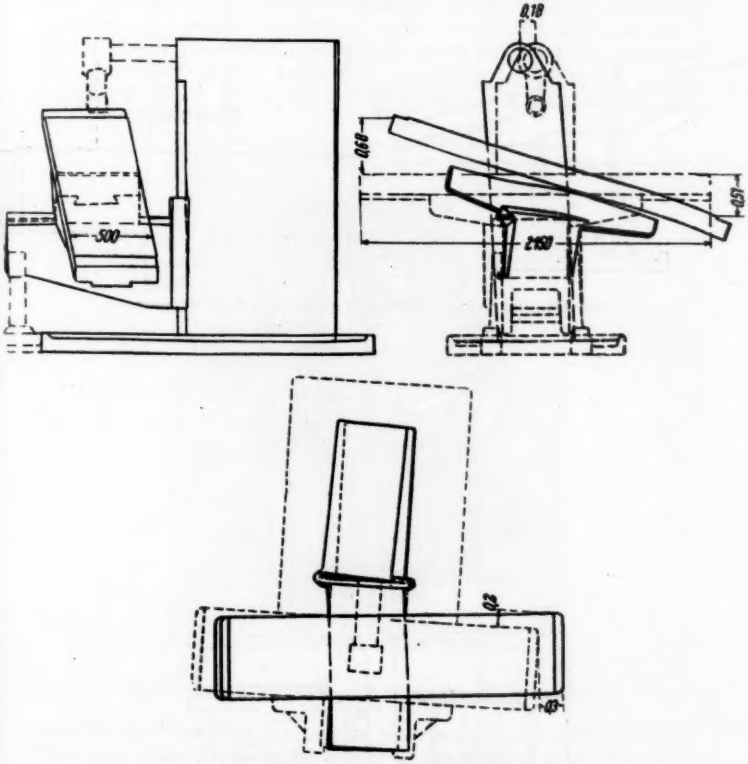


Fig. 22.—Distortion of Milling Machine without Support under Knee.

arrangements of multiple cutters are not provided for in the inspection book The stipulations as to the necessary power and precision of machines for such work should be stated in the contract for the machines.

Distortion under Heavy Cuts.

For heavy cuts on a milling machine a support is usually placed under the end of the knee. Without this support it will be observed how the various sliding connections—the knee on the column, the

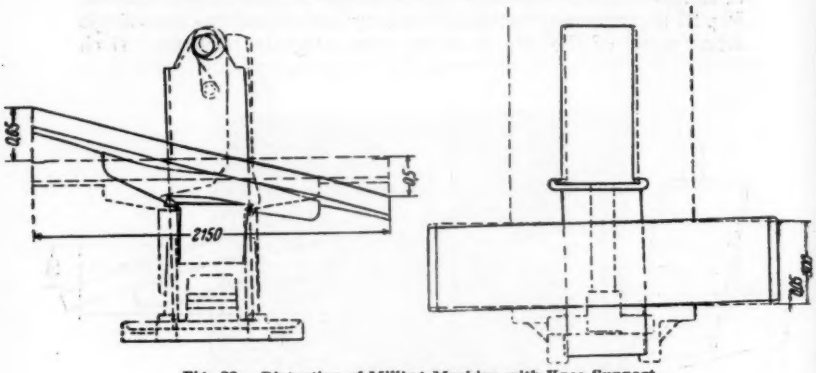


Fig. 23.—Distortion of Milling Machine with Knee Support.

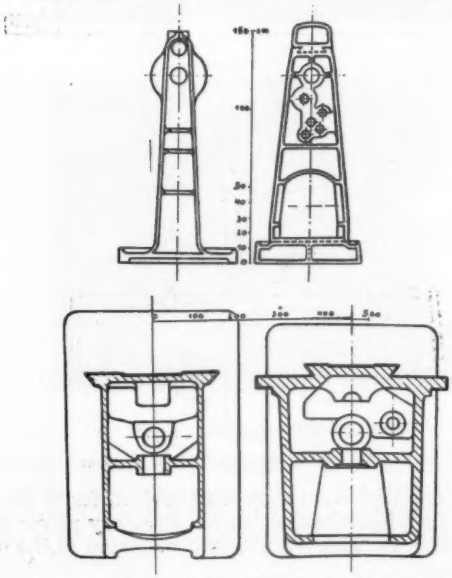


Fig. 24.—Widening and Strengthening Column and Knee

slide on the knee and the table on the slide—tend to act as joints about which distortion may take place. An instance of this distortion is shown in Fig. 22, which shows the effect of utilising to the full extent the 10 h.p. motor of a certain machine to take heavy cuts without the knee support. The table has been tilted vertically by 0.68 mm. (0.027 in.) at one end and 0.51 mm. (0.20 in.) at the other, and in the horizontal direction by 0.3 mm. (0.012 in.). Any work produced under these conditions would be correspondingly distorted in shape to an extent well beyond the usual accepted limits. By introducing the support under the knee, the effect of the movement at the knee slide is eliminated, Fig. 23. The horizontal tilt of the table is reduced from 0.3 mm. to 0.05 mm.

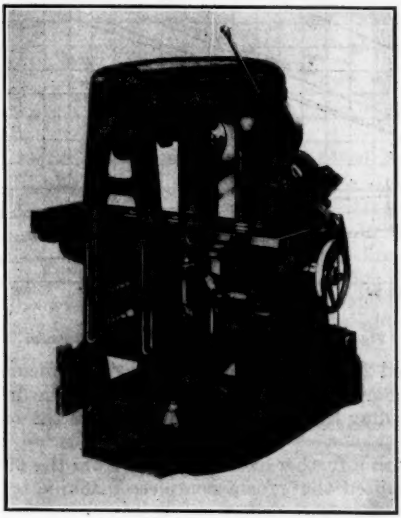


Fig. 25.—Archdale Machine with Knee Supported and Braced.

(0.002 in.) but its tilt in the vertical place remains the same as before. This knee is badly designed as the guiding surfaces are not wide enough. If milling machines of the knee type are to be used for heavy cutting the column and knee should be widened and reinforced in a suitable manner to withstand the forces as shown to the right of Fig. 24. In addition, the knee should be braced to the column as in Fig. 25, to minimise the tendency for the table to tilt under the cutting forces.

Efficiency of Cutting.

In a milling machine, the power is used in a different manner as compared with a drilling machine. This will be seen by comparing Fig. 26 with Fig. 9. The machine to which Fig. 26 refers had two motors, one for driving the cutter and the other for the table feed.

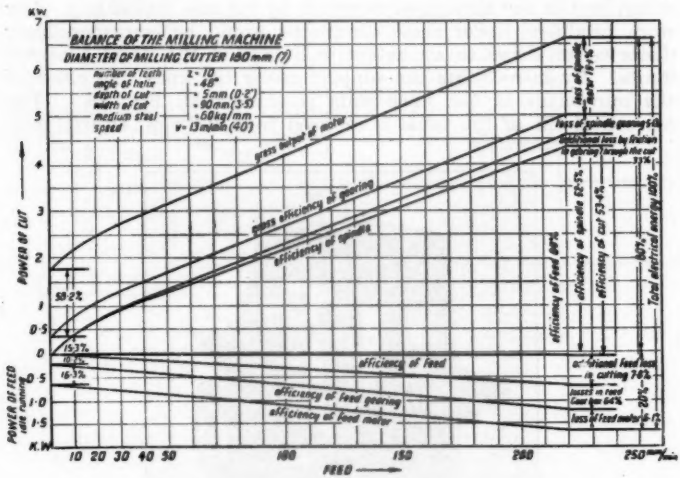

BALANCE OF THE MILLING MACHINE
DIAMETER OF MILLING CUTTER 190 mm (7")
number of teeth Z = 10
angle of helix = 45°
depth of cut = 5mm (0·2")
width of cut = 90 mm (3·5)
medium steel = 60 kg/mm
speed v = 13 m/min (40')
POWER OF CUT
POWER OF FEED
K.W
FEED
gross output of motor
gross efficiency of gearing
efficiency of spindle
efficiency of feed
efficiency of feed gearing
efficiency of feed motor
efficiency of feed 49%
efficiency of spindle 62·2%
efficiency of cut 53·4%
Total electrical energy 100%
59·2%
15·3%
16·3%
10 20 30 40 50 100 150 200 250 mm/min

Fig. 26.—Power Diagram of Milling Machine.

The latter used 20% of the total power. The efficiency of the feed was 0.9% as compared with 0.5% in the case of the drilling machine. The corresponding figures for the efficiency of the cut were 53.4% and 65.6%.

To finish with a further example taken from the milling machine, it must be realised that, for a complete machine to pass the final

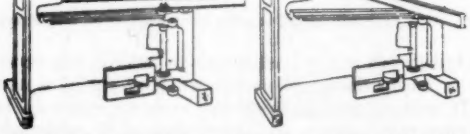


Fig. 27.—Testing Slides on Column and Hole for Spindle.

inspection, it is necessary to organise every stage of its manufacture with the view to attaining the desired degree of accuracy. This necessitates educating all the mechanics concerned to precise work.

If the necessary care is not taken at each stage of the manufacture of a machine with the result that the machine when completed fails to pass the final tests, it is a very difficult matter to rectify the faults at the end.

Let us consider the various stages in the manufacture of a milling machine. The guiding surfaces on the column and the holes for the driving spindle must be planed and bored so as to be accurately square in the two planes, Fig. 27. The knee is planed and finally

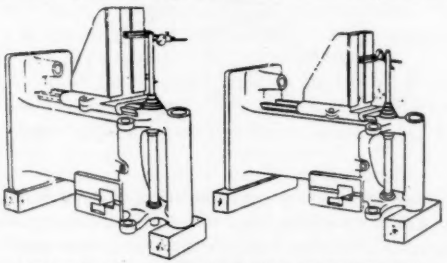


Fig. 28.—Testing Surface of Knee off Spindle Hole.

fitted to the column whilst the latter is horizontal, Fig. 28. In doing so the face of the knee is made square transversely, but in adjusting it parallel to the spindle hole, a certain allowance has to be made for the downward deflection of the knee which occurs when the machine is finally stood upright. This deflection is due not only to the weight of the knee itself but also of the slide and table when they are fitted to it, Fig. 29. The allowance must, of

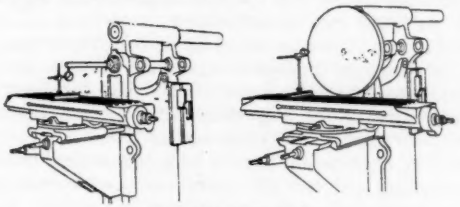


Fig. 29.—Testing Table.

course, be known beforehand and the fitter instructed accordingly, otherwise the machine will not pass the final inspection.

In addition to the truth of its rectilinear movements, the universal milling machine has to satisfy certain conditions regarding the swivelling movement of the turntable which is made use of in cutting spirals. The axis about which the table turns must be square to and also pass through the axis of the spindle, Fig. 30. To arrive at this condition demands care not only on the part of the designer,

but also whilst the various members are being fitted together during the course of construction. This example of the milling machine shows the necessity for the closest co-operation between the designer and the manufacturing side.

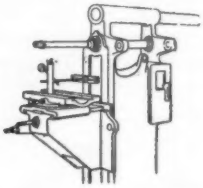


Fig. 30.—Testing Swivelling Axis of Table of Universal Milling Machine.

Summary.

In testing machine tools consideration has to be given to the effect of the forces to which they are subjected upon the degree of accuracy desired. For this purpose the particular conditions under which each type of machine operates must be studied and any necessary data obtained experimentally by accurate measurements.

If an international testing-code for machine tools is to be thought of it should be based solely upon the quality of the tools desired. The specification of the accuracy should be commercially possible at reasonable cost, but it should be high enough to exclude all inferior production. On this basis there appears to be no reason why one degree of accuracy cannot be specified for all normally good machine tools. Which code of inspection is agreed upon is immaterial provided general agreement is arrived at. It may be mentioned that, up to the present more than 150,000 machine tools have been accepted on the Schlesinger code of tests and they have all given satisfactory results in practice. The tests comprised not only measurements of the alignments of the machines but also of sample pieces of work actually finished in them.

At the end of each test sheet in the inspection book you will find data regarding such test pieces and the best procedure for carrying out the inspection, since experience has shown that foreign inspectors are apt to adhere rather too rigidly to every table of tests which is given in the test sheets with the result that the inspection is made unnecessarily protracted and costly.

For the inspection to be carried out at reasonable cost it should be possible to examine the fully assembled machine as a unit. One hour should suffice for setting up a machine from stock and testing its alignments. It will be understood that if the machine is to be tested under full working conditions it becomes necessary to spend time fastening the machine to a foundation plate and setting

it up under a belt or coupling up its motor. Coolant usually has to be employed in these tests and time has to be spent subsequently in cleaning the machine. Further the machine has to be run long enough for the tools to become blunt. Should such tests under working conditions be demanded they should be agreed to beforehand in the contract.

In general it is assumed that every machine is subject to examination by the production of a test-piece as laid down in the inspection book. Provision is made for this in the test-sheet. The report on the testing is signed by the inspector and the manufacturer and a copy is sent to the purchaser with the machine.

It is supposed that the machine will be set up by the purchaser in the same careful manner as when tested, in which case it will show the same precision. This guarantee is given by the manufacturer provided the setting up is satisfactory. It is understood, of course, that the machine must not be badly treated in transit. If it is dropped, for example, its accuracy may be entirely lost.

It would be a great honour, in fact the crowning of my life's work, if the Schlesinger code of machine tool inspection were adopted internationally. I am always ready to listen to any criticisms of my code and am prepared to accept any reasonable proposals for its improvement. I may say that the main idea I had in mind in producing the inspection book was to provide for manufacturers of metal and wood-working machine tools a definite basis of accuracy which would satisfy the requirements of the user and yet be quite practicable to the manufacturer himself.

It is recognised that the quality and accuracy aimed at may, in the early stages, only be attained by the better equipped manufacturers, but as time goes on it is hoped that the whole industry of machine tool manufacturers will be educated up to the higher standard. It is generally recognised that any increase in the accuracy of machine tools has the much desired effect of producing a corresponding improvement in the quality of the work which is turned out on them. This improvement is reflected in its turn in the general standard of living of the nation and any efforts in this direction are obviously well worth while.

Discussion.

MR. B. C. JENKINS : In rising to open this discussion I must ask your indulgence if my remarks are not distinctly applicable to the paper itself, but they are at the same time relative to the paper and what the paper provokes in my own mind as a production engineer concerned with the choice and purchase of machinery and the product which comes from such machines and what is possibly more essential still, the maintenance of such machines. The paper which Dr. Schlesinger has given us interests me as a very scientific exposition given in a manner which can be appreciated by most practical men.

The first thought which reaches one's mind is the absolute necessity for some standard of accuracy whether it be that laid down by Dr. Schlesinger or some other standard. It is obvious we should have some standard of measurement from which to check back not only new but overhauled machines.

In watching the various illustrations of machine deflection shown by the lecturer, it made one wish that those people to whom the production engineer is responsible, works managers, managing directors, and so forth, could have been present. What excellent alibis we could have raised for failure to produce components to the ten thousandth part of an inch tolerance which is now demanded in many production shops. My main impression is the necessity for machine tool manufacturers in this country to study and analyse this book of Dr. Schlesinger's, and to go back and analyse their own methods, machines, and tools which they use to produce the machines they sell to us. In saying that I must pay tribute to the excellence of the machines turned out with such equipment.

When a machine tool salesman talks to me about the obsolescence of any class of machine we may be using and the necessity and wisdom of replacement, it always calls to my mind many of the machine tool shops I have been in and the poor condition and class of equipment used to obtain the degree of accuracy which is necessary to their product. It is a remarkable thing to me that they get the degree of accuracy they finally achieve.

There are one or two firms of machine tool manufacturers in this country very well known to most of you who issue charts showing the degree of accuracy they maintain in their products. In the past few months we have had an opportunity of actually checking up a machine from such a chart ; the machine was checked over by a mechanic who knew nothing of the tolerances laid down in the chart supplied. He was given directions as to the method and

dimensions to be checked, and in practically every item the machine was found to conform to tolerances laid down by the manufacturer.

The machine is giving excellent results as would be expected, and as a natural consequence when I am again in the market for that class of equipment I shall buy more machines of that maker's manufacture. I think that the average production engineer who knows his business and has any thought for the welfare of his firm, will adopt the same attitude. Machine tool producers who are prepared to go forward and conform to a satisfactory standard of accuracy are going to get the business of every thoughtful production engineer: that sums up the position.

Why was a certain American tool room lathe regarded as standard for highest grade tool work for so many years? Why do we buy for preference machines from given manufacturers? Obviously either because we know the close standard of accuracy maintained in manufacture or from personal knowledge of past performance. In many cases we buy machinery on past performance and past evidence only.

Other manufacturers offer machinery of the same type apparently well designed and made, but owing to the absence of comparative standards of accuracy we are forced to buy from well-known firms for reasons of safety and protection. If other firms intend to get into the business and compete successfully with firms who work to acceptable standards of accuracy as proven by past performance, I feel sure they must of necessity be forced to adopt standards such as those laid down in Dr. Schlesinger's paper this evening.

DR. SCHLESINGER: I think it is a mistake to buy always machine tools from the same firm, because it has had a good reputation and on account of some bad experience one made once with another designer. This stops development. The inspection of machine tools ought to be impartial. The idea is to watch the accuracy of each single machine—also of those from a firm with good reputation.

If the British machine tool makers as a totality have to furnish, e.g., the Russian Government as a monopolised buyer, you can only base your business on impartial lines. The Russians will try to get the machines as cheaply as possible—they can claim it—and then they will use the cheap offer to cut the competition both of the firms of good repute and for high-classed machines. The inspection book took its origin as an arbiter's sentence between the Russian client and the German manufacturer. In such cases an inspection-code is the best helper for both sides. The beginner who has not yet a reputation can compete if he fulfills the rules of the inspection-book. Then he must be a good manufacturer, too. But he can hardly sell cheaper because the test-charts impose on him about the same kind and expense of manufacturing. You, as the buyer, however, are sure to get a good machine, not because the salesman

is a good talker and is fighting under the strong backing of the good reputation of his firm, but because he has to prove the quality of his products. The design however is not codified; the design is the peculiarity of the engineer. Only the workmanship is put under established rules by the inspection and this is, I believe, a good thing.

MR. A. SYKES: As a visitor to your Institution may I be allowed to thank you for the opportunity of being present with you this evening. I think we have had a paper of very deep interest, both to manufacturers and users of machine tools. One cannot help but feel great admiration for the work which Dr. Schlesinger has done. He has accomplished almost single-handed work which in the ordinary way would be regarded as sufficient for a whole Institution. I believe that it was the aim in this country to do something of the same kind, but we have not got very far, largely, I think, due to the fact that Dr. Schlesinger has done his work so well that it has been felt there was not much more to be done. He has seen his work accepted not only in his own country, but in many other countries, and it has been accepted by the manufacturer and the user, both by the buyer and the seller.

In the paper which he has given us this evening we have seen that he has gone further than merely to standardise the tests. He has done something to show how the machines should be designed, and the forces we have to resist and how we should provide against these forces. The introduction to his book on tests is in itself worth while reading. It shows that he has studied the subject very thoroughly and that he realises not only the necessity of practical tests, but at the same time he realises the difficulty of making these tests and the necessity of not creating an unnecessary waste of time in doing them.

I gathered from his remarks that he considers it useless to apply his tests for machines used for roughing only. I would like to ask him one or two questions. I gathered that he said his test is most applicable to finishing machines. Now in finishing machines we expect high speeds and light cuts. In roughing at high speeds he has pointed out the necessity of having roller bearings. We also find that when we get these high speeds we are likely to have more than an average temperature. Has he made any investigations to show how to allow for temperature rises and to assure us that we are going to get the same degree of accuracy under working conditions as we get from the tests?

There are one or two other points also that I would like to raise. I have often wondered about some of the limits of accuracy given in connection with lathes and grinding machines as regards centre height. I notice that he generally gives a very fine limit for the height of centres and it often seems to me that when you are working

with a tool or grinding wheel on the horizontal centre line the necessity for accurate centre height is not so great as he has indicated. As an example he mentions that the allowable variation in the height of a grinding wheel is 0.2 mm., and when he sets a limit for the centre height between centres he reduces that limit to 0.02 or one-tenth. I have always felt that that particular limit is unduly fine.

Another point which has struck me is that in fixing his limits for lead screws he gives an error per foot length, but he says nothing about the short distance errors—the periodic errors that might be caused by irregular thrusts, or other causes.

DR. SCHLESINGER: Mr. Sykes asks first for investigations for temperature. We measured the temperature for the general cylindrical bearing and found, that if you surpass 60°C. there is danger, if you use the usual machine oil in the drill press, lathe, or milling machine (Engler's viscosity 5-6°) 60°; is about the maximum that the human hand can stand by touching the bearing from outside. The grinding machine has mostly higher temperatures, even if you select the right oil for the spindle of the grinding wheel (viscosity 1.5-2°). The grinding machine works with small forces. With a wheel of 2 in. wide and 20 in. diameter the highest force is about 100 lb. That is small for a machine tool. If you see that the oil is pressed through the bearings by the shape of the oil grooves or an oil pump or by some other means, no danger is incurred. For ball and roller bearings the friction and therefore the rise of temperature is much less. I do not think there is a ball bearing in existence that is heating up to 60°. Here you must avoid having too much oil. That is the reason why you can diminish the tolerances; that is depending from the "play of oil," disregarding the numbers of revolution. You may easily adjust the play of a ball bearing or a roller bearing down to 0.0001 in., but you cannot go down to less than 0.001 in. in a general plain bearing. You must have a certain thickness of the oil film or the friction, i.e., temperature rises. That is all we have measured, but an article written by Dr. Kurrein on plain and roller bearings for transmission lines of high velocities will give you more help in this direction. (Report of the "Versuchsfeld of Werkzeugmaschinen—Julius Springer, Berlin, 1932.)

The second point was why in the lathe and grinding machines the height of centres is tested so accurately, especially for the grinding machine. The accuracy is only necessary for *taper* grinding. The grinding machine is designed to finish very slight tapers, e.g. for the spindle bearings of the main machine spindles themselves. The cone varies generally between 1 : 10 to 1 : 12. For that purpose the upper table of the grinding machine is always turnable. If your grinding wheel is not very close to the centre height you do not grind a straight line cone, but an hyperboloide with curved flanks.

That is the only reason. The third question concerned the lead screws. The limit is 0.03 mm. to 300 i. that is about 0.001 in. to the foot, a bit more. You find in the introduction of the inspection book, that this ought to be plus and minus in the reversed sense, and it ought not to be more than 0.1 mm. to 1000 mm. length. If you want more accuracy, of course you must pay for it. But the figures you find in the inspection book are not guaranteed. They are only assured. That means that if you wish to have a guarantee you must apply to the Board of Trade or the National Physical Laboratory and have a special test made. The short distant errors and the periodic errors may result from pitch errors of the gears in the Norton gearbox or by axial slip and finally by non-parallelism of the end washers of the lead screw bearing. For the ordinary lead screw they must be all within 0.001 in. per foot.

MR. J. D. SCAIFE: I should like to have the opportunity, Mr. chairman, of thanking Dr. Schlesinger for giving us the honour of coming all the way from Brussels to give us this paper. I think that the Institution has been honoured in Dr. Schlesinger coming all this way.

There are one or two objections I have found to be lodged against the adoption of Dr. Schlesinger's limits. One is the apparent extra cost of working to the limits, the other is the fear that if one buys or sells orders with a proviso that the machine must be tested to Dr. Schlesinger's limits it would introduce a lot of nuisance in the way of inspectors coming round your works with microscopes and X-rays and things like that, and generally giving you more trouble.

Well, our own experience has been quite otherwise. The slight extra cost of instituting the Schlesinger system in the works has been more than offset by the saving in ultimate rectification. That is, we find that if we adhere to the tests we ultimately get very much better results in the testing of our machines, and lower costs. We have found actually that we have saved money by introducing these tests and have improved the product. With regard to the inspector bogey, we have not been worried by that because we find that if we show that we are working for these tolerances the inspectors are more easily satisfied and they do not impose some extraordinary fancy limits of their own. We actually have a safeguard.

MR. G. H. WRAY: I hope there will be a practical outcome of Dr. Schlesinger's visit, and that the machine tool manufacturers of this country will establish standards of limits of accuracy of machine tools, and where they shall be measured.

Let us look at this problem from a practical point of view. An inquiry is sent to various firms for a particular machine tool, but when the quotations are received, the limits of accuracy to which the machine will be made are rarely given. If they are requested,

a good deal of mathematical work has to be done, before comparisons can be made, as the basic measurement by different makers is not an agreed figure.

It has been said by suppliers that the customer should specify the tolerances, and the machine tool manufacturer will give us any limits of accuracy we require so long as we pay for it. This is fundamentally wrong. If a machine tool maker puts on the market a new type of machine, of which he expects to sell 1,000 machines, these machines may be sold to 500 different customers. Surely he does not want a large number of requests from firms, specifying different tolerances. If so, then a machine cannot be purchased from stock, or on a short delivery time, and every machine will have to be specially built.

I think it is time that the British manufacturers got together to establish some standards, which would give us a guarantee of the accuracy to which machine tools are made. In the present circumstances, if you buy a machine from a British manufacturer and it does not produce work to the limits required, it cannot, at least theoretically, be rejected, because no guarantee has been given. I hope that our machine tool firms will adopt some basis of measurement as an outcome of this lecture.

DR. SCHLESINGER: I think that the manufacturers should have some standard for every machine. There is no excuse then to introduce inaccurate machines, and you are sure that all these machines are of the same class of workmanship. It would not be necessary that their price be increased perceptibly, if the organisation of the total manufacturing is correct.

MR. F. TURNER: I should like first of all to thank the Institution of Production Engineers for permitting me to come as a visitor to this meeting and to have the opportunity of hearing Dr. Schlesinger. Secondly, I should like to offer my congratulations also to Dr. Schlesinger for the work he has done in connection with the alignments of machine tools and for his admirable address this evening.

I gathered from Dr. Schlesinger's early remarks that the power absorbed in cutting steels with carbide tools is proportional to the rate at which material is removed. On the other hand I have recently heard of cutting trials at very high speeds—upwards of 600 feet per minute—which appeared to demonstrate that beyond a certain point the power required was not proportional to the rate of removal of material. Can Dr. Schlesinger tell us anything of these recent experiments?

In regard to the drills, of which a picture has been shown us, with a spiral flute having a less acute angle with the drill axis, does not difficulty arise in getting rid of the chips? A recent speaker spoke of limits of inaccuracy being laid down by the manufacturer. I suggest that it is rather the duty of the user to say what limits he

requires for his machine than of the manufacturer who cannot have quite the same knowledge of the production required. Our experience is that if limits of inaccuracy are set out reputable firms will be prepared to work to them.

In Dr. Schlesinger's book the idea seems to be suggested that there should be only one set of limits and I thought the Doctor's remarks to-night confirmed that point of view. I feel on the other hand that more than one set of limits might be laid down ; two grades or possibly three. A drilling machine for a boiler shop, for instance, would not require the same grade of tolerance as a drilling machine in, say, a motor car works.

One more point I should like to raise in regard to Dr. Schlesinger's recommendations—his suggestion that final test of the machine must always be at the machine manufacturer's works. I want to suggest very strongly—as a machine user—that the final test must always be at the user's works. It is not sufficient that the machine manufacturer should be able to show an accurate machine at his works. His design must also be capable of withstanding stresses imposed upon it during transport. I suggest that final alignment test at the user's works should be taken after the machine has been run at its full capacity.

DR. SCHLESINGER : Well, the questions you raise are very deep and show you have read the introduction of the inspection-book very carefully, perhaps more carefully than I know it by heart to answer them in detail.

You spoke of first class and second class machines. Allow me to read the corresponding paragraph : "Where only medium or even loose fits are required, the use of high grade machine tools as described will not always be necessary. In such cases wider tolerances, exceeding the values given by 50% to 150% will be sufficient, depending on the work to be performed. The increase in tolerance will not apply to all measurements of a test chart equally. Thus, in any such case for which the tolerances given will not constitute the basis of the trial test to be made with a machine tool, particular arrangements as to the closeness of the tolerance factors should be made before signing the contract between maker and customer. And the price of the machine will, of course, depend on the arrangement regarding such factors."

Some organisation work must be done with regard to this question. Generally it is sufficient to tell the manufacturer what you want. But then you have the responsibility of describing your wishes. But if you believe that in increasing the tolerances by 50% you will get the machine for 50% less, you are mistaken. Futhermore consider earnestly : "You cannot manufacture in the same shop a first class and a second class machine. You diminish the level of all the workmanship." I was always very glad if I had to make

machines of the same standard of workmanship, with the same tolerances, given in the rules ; then the workmen had to work according to a stipulated accuracy.

You asked about the fall of power absorbed by cutting at very high speeds. If you go up to 3.000 ft./min., that is the speed at which we turned electron, even up to 4,500, then you are in the region where the power is diminished in another ratio than proportional to the rate of removal of material. There is a patent taken by the firm of Krupp (DRP 523,594/1931) which determines this limit from about 600 metres = 1,800 ft. upwards. It is only available for light metals such as aluminium and its alloys where the cutting forces are so small that you can do the work with a motor of reasonable dimensions. The formula $HP = \frac{P \cdot v}{75.60}$ demands that the motor is proportional to the speed v. My own tests within the normal limits up to about 500 ft. proved that for the same chip the power P remained the same if you were cutting with the usual speeds from 50 ft. or 500 min. (Comp. " Schlesinger : Die Werkzeugmaschinen—Julius Springer, Berlin, 1936, page 4).

Dr. Salomon, the late chief of the laboratory of Ludw. Loewe-Berlin investigated the quick-running milling tools by an ascillograph. His doctor-dissertation is published at the Munich Polytechnicum. You will find all the data you want therein.

Furthermore you spoke of the angles of the twist-drill. We examined one drill of 12° and one of 45° in drilling electron. The thrust was made constant and you have seen the diagram for this drill. The feed force increases quickly and then the drill of 12° flute stuck and broke. Then the cutting angle was changed to 36° and 45° and the chip-curls came out without difficulty (read the doctor-dissertation of Lingemann-Berlin, Technical High School 1932). It means that for aluminium and its alloys you ought to change the spiral flute considerably.

Finally you objected that in the book there is a statement made that the machine is to be inspected at the makers work ; but there is an explanation for that. The customers don't possess as a rule the total apparatus to do the inspection : with milling and grinding machines, drill, presses, boring mills, lathes, etc., and you have not the staff for inspecting either. But you get the measured accuracy of the machine by the inspection-chart of the deliverer and you may check up the data if you like. You have only to set up the machine correctly, of course.

While I was in the sales-department thirty-two years ago, I had sometimes to fight with clients in France, Italy, Great Britain, etc. There was always a letter saying, that the machine was out of true and that it should be rejected. I took my little bag with a hammer, two

levels and about a dozen very flat wedges, made the voyage to the client and said to the foreman: "Take the screws out of the foundation, put the wedges under the legs. Then you take the hammer and I watch the levels." An hour later I left the shop and the machine was all right. It occurred often too that the bed was twisted by the driving qualities of the cement. The heaviest machine can be twisted within more than the limits if the cement is bad. We sent the instructions for setting-up the machine to the firm and generally stopped such further claims. But we were sure of our high workmanship. Already in 1902, when I was a shop engineer of Loewe-Berlin, my firm did international trade and we found, that it was very good policy to send the checked-up test charts to the customers. We knew that a trip of a fitter from Berlin to Huddersfield to set-up a machine cost more than the profit to us for the whole machine. The machine tool is not a steam engine or a motor. It is not allowed to be tipped over on the transport. Generally something has happened on the way. Therefore my remark in the inspection book. The design of a machine tool can hardly withstand unusual stresses during the transport, specially if it stands free on the waggon. Then you must ship it by a correspondingly strong package.

EX-PROVOST LANG: It was Dr. Johnson who said that it takes a surgical operation to put a joke into a Scotsman's head.

I do not think there are many Scotsmen here but I hope you will allow me to foist on you a joke, or at least try to.

A little boy was fishing in a country stream one day and while he was fishing he managed to fall in. He was in due course rescued and when he was standing on the roadway looking very wet a kindly old lady came along and seeing him said, "My little boy, however did you come to fall in?" The little boy looked up in wonder and said, "I did not come to fall in, I came to fish."

Well, Mr. Chairman, I have come probably farther than most people to-night, for I have come 400 miles to hear Dr. Schlesinger's lecture, and I am not going back disappointed. I did not come to speak. I came to listen and learn, but after listening to a gentleman behind me, to a voice I recognised at once, Mr. Wray from not 100 miles from here, I could not help feeling that it was my duty as President of the Machine Tool Trades Association to make an explanation.

Some time ago the executive of the Machine Tool Association of which I am now President discussed as to whether there should be standards, British standards, of limits for machine tools (and after some preliminary discussions the question came before the Machine Tool Trades Association). I would like to say to you with great earnestness that the question was taken seriously. It was discussed from every point of view. The Association through its

important members communicated with Germany and with America before coming to a decision, and finally the decision was quite clear and quite decisive, "that it was not desirable to have British standard of limits set for machine tools." If I were to attempt to give you all the arguments that were brought forward it would take as long as Dr. Schlesinger's talk to-night and I do not propose to do that. As President of the Association I am telling you gentlemen who are production engineers, and who are both buyers and users, that this matter has had the most serious consideration and the present decision is that the Machine Tool Trades Association is not in favour of standards, apart from those made by individual firms or companies.

Now while I am speaking I want to say this—that I came here to listen to the Doctor speaking on Machine Tool Tests and Alignments and I want to say frankly that I have been very much more interested to hear the lecture as delivered because it was far more interesting to me than one purely on tests and alignments.

Now I do not want to keep you long. The Secretary invited me here to-night, but I said he was not to call on me but that if I felt like it I would speak.

I feel a difficulty. I have not come here on business and it is so difficult speaking to a body of gentlemen like you on machine tools without making some business reference, however anxious one is not to do so. I was brought up amongst lathes and have been connected with them for over 50 years. We have many kinds of lathes and I can say to you gentlemen who have favoured us with orders in the past—and I am not suggesting that you should favour us with orders in the future—that we have tests and the alignments for every lathe that we have made during the last 30 or 40 years. It shows that in principle we are whole-heartedly in agreement with the idea of having tests and alignments. So are most other machine tool makers.

Let me say this one thing very strongly. Mr. Turner brought up the question and I think he was suggesting that the Doctor led us to understand that he was inclined to think there was for machine tools one set and one set only. I also took him to mean that, although I knew that in his book he made quite a different case. But in this country it may be that the differences we have are rather greater than those in America or Germany. It is difficult to keep from talking shop when I am trying to explain a situation, but the case I am trying to make is that in this country there are people who make machine tools for abroad—in very cheap markets—and if we stultify a company of that kind it might affect quite seriously the export of machine tools which are at present a valuable asset.

Allow me to give one instance. There was a lathe in the last exhibition. I know the man who makes it very, very well and he

won't resent my making this statement. On his stand was a 6½ lathe and on it a large placard bearing the price £52 10s. That was the selling price. On my company's stand was also a 6½ lathe—just the same weight—and the price of the material that we put in that machine was £54.

Now I do not want to take up your time. But I want to say this—that I have come here to-night from a very long distance. I have enjoyed the lecture very much indeed, and have learnt a lot from it. I don't think Dr. Schlesinger will mind me saying that I did not know he was a traveller for machine tools. He will have definite sympathy from some of us who are trying to fight the battle.

Please do not go away with the misunderstanding that the Machine Tool Trades Association is not alive to the seriousness of our position. I am not going to say what will take place in the future but I want you clearly to understand that we have discussed this very seriously and the decision of the majority is quite definite.

There was one point which I was very interested to hear. If I gathered aright, the Doctor said that you could not turn steel at 1,800 ft. a minute. I do not know whether he said that or whether he meant it, but in our own works I have seen 40 tons tensile steel being turned at 1,500 ft. a minute. We have never risked going on any higher, but the modern cutting alloys are capable of almost any cutting speed that you like to impose upon them.

My final words are of appreciation and thankfulness that I have been allowed the privilege of coming to this meeting and hearing the lecture and the speakers who have given us their views.

MR. J. PICKIN : I was reading in the *Engineer* a little time ago a paper by one of our industrialists and I remember very well one sentence. It was to the effect that Science is the soul of Industry, and that no industrial concern which fails to take advantage of the benefits of science can long continue to prosper. Well, I think we industrialists ought to pay a tribute to Dr. Schlesinger for pointing out, in such a clear and forceful way, the great benefits which can accrue from a scientific consideration of the design of machine tools, and I should like also to offer my personal thanks to Dr. Schlesinger for his most interesting and instructive lecture.

On the subject of standard limits perhaps I might say something. The firm with which I am connected is by no means opposed to standards. It was among the pioneers in its own industry of the use of standards to the very fullest extent. We have our own standard alignment limits and test limits which we are always ready to show to our customers, but we do honestly think that any attempt to lay down definite national standards would be dangerous ; it seems to us like trying to standardise quality.

MR. R. BROOMHEAD : I certainly would like to pay a tribute to the explanation and the way in which Dr. Schlesinger has illustrated

to us the way that machine tools should be measured. As one who has been in the business for many years, particularly on tool room work where troubles arise in the shops and the men cannot work to this gauge or that gauge, it has been my duty and privilege to go along and find where the trouble was, and one gets more or less so accustomed to this sort of thing that it loses its significance. During the last twelve months it has been a matter of great interest to me that the Institution of Production Engineers has inaugurated a Standards Committee, a main object of which is to help the British Standards Institution. This question of machine tool limits has come up on more than one occasion. It has been discussed from various points of view, and one feels very concerned when we have had confirmed to-night by our dear old friend, Mr. Lang, that the machine tool builders are not in favour of the adoption of Dr. Schlesinger's Standards.

It has been my privilege, on more than one occasion, to be called in to a new machine worth almost £1,000 and to find that the product of it had not come up to the standards that we required, and upon investigation, I personally found that the product from that machine did not come up to the standards as laid down by Dr. Schlesinger's book. I should be very pleased, and consoled, to know that the visit of Dr. Schlesinger here this evening, had made a great impression upon the machine tool builders in this country.

With regard to Mr. Lang's point—that is that there are some machine tool makers who prefer to make a cheaper machine which obviously is not accurate. Of course as I take more or less a tool room point of view I personally would prefer to see these people go out of business, so that we as production engineers, could have machines brought into our factories doing accurate work, and guaranteed to do their job without any further trouble. We have had trouble with lathes also, and I am convinced that if our machine tool builders were only to work to Dr. Schlesinger's limits we should have less trouble in the shops, and longer life from the machines.

Mr. W. J. Lewis, M.B.E., : I want to thank you for the privilege of allowing me to come to your meeting to-night. I have been looking forward to seeing and hearing Dr. Schlesinger, whose past work it has been my pleasure to read. In the first place, did I understand Dr. Schlesinger to say that machines made to his tolerances do not cost more than those made to lower standards? My own experience is that the higher the standard of accuracy demanded, the higher is the price; and this is what I should expect. Confirmation, or otherwise, is therefore desired as to whether my impression of his opinion in this respect is correct.

Secondly, I understand that Dr. Schlesinger advocates the making of all machines to his standard. I doubt the necessity of all machines requiring to be made to such a high standard of tolerance. The

need of such a standard is clear in the case of machines engaged in toolroom work, gauge making, and a certain amount of production work, but a great many machines employed in general engineering, shipyard, and repair work do not need to be made to such a fine degree of accuracy, or of "inaccuracy" if this nomenclature is preferred. In any case it is obvious, as the author observed, that machines required to turn out work of a high order of accuracy cannot be expected to do rough machining as well.

Finally, I would like to add that my own experience as regards the purchase of machines for work of special accuracy is that this can be effected satisfactorily by specifying the accuracy to which the product has to be finished, leaving the machine tool makers themselves to decide from their own experience the standards to which the various parts of the machine need to be manufactured to comply with the specified limits of the product.

I have found that British machine tool makers of standing are prepared not only to manufacture machines capable of demonstrating the required degree of accuracy at maker's works, but that they are prepared to take full responsibility for delivery, erection, and a product test at client's works as well. Moreover, I find no difficulty in obtaining a guarantee for twelve months after acceptance, against any defect arising from faulty design, material, or workmanship, which gives the customer full opportunity over a lengthy period of proving the efficacy of the machine to perform the service required.

I will confine my remarks on this occasion to these few points, but would like to add my tribute to the thoroughness with which the problem of machine tool construction has been tackled by Dr. Schlesinger. I should be pleased if he would give his views on the first two points of my remarks.

DR. SCHLESINGER: Mr. Lewis desired an answer on his first two questions:—

(1) Are the machines built after the tolerances of the "Inspection Book" not more expensive than those after the lower standards?

(2) Is it really necessary to inspect all the machine-tools after this high standard of test?

(1) Of course, the costs for first class machines after the test charts are a little higher than those for the ordinary ones. But the fact exists that after introduction of the tolerances the selling prices of the German machines have been raised no more than 5-6%, and in some cases not at all. The purchaser should be quite clear that a well manufactured machine generally is also of a good design, easier to handle, of longer life, and requires less maintenance. It is therefore in any case cheaper to use than the "cheap" machine.

For machine tools and tools we must apply the known word:

"I am not rich enough to buy a cheap machine." The used cast iron, e.g., is better. At good machines a Brinell-hardness of 180 points — 10% is used. At cheap machines we find only 120 to 140 points. From this knowledge the market for good machines has become greater and greater for good machines and the machines of medium quality have decreased.

With that I come to point (2), if it be expedient to introduce two kinds of reception for good and medium machines.

My point of view is, that cheap and not so well manufactured machines suffice of course, for instance, for the forge of a village, but a great number of machines are yearly pushed out of big factories which still are good enough for this purpose. Those are then the second-hand machines and we should distinguish between good and second-hand machines. For the latter coarser tolerances are sufficient.

In connection with this I may be allowed to make some personal observations with regard to the remarks made by Messrs. Lang, Pickin and several of the former speakers.

The manuscript of the "Inspection Book" was first finished in the year 1909 and it was put before the "Association of German Machine Tool Builders" in 1910. Its fate was then the same as the rejection of to-day by the "British Machine Tool Trades Association." The German Association considered the publication of such a book at that time as dangerous, for the same reasons as those given to-day by Mr. Lang. Then the Russians, in 1925, gave a big order to Germany, and they already possessed test-charts of the finest American firms as well as of the very best German firms. These prescriptions were at that time still more severe than those chosen by me finally, because they referred to machines with especially high precision. In 1925 and 1927 I had sufficient opportunity to study thoroughly the Russian needs in the country itself. At the same time great difficulties arose between the German makers of tools and the Russian client. At this, written confirmations of American, German, and English firms were given and their exaggerations had to be examined carefully by me with regard to the precision. By this I was charged, by both the Germans and the Russians, to publish an "Inspection Book."

The tolerances given in this book are 99% based on my own experiences, which I made and collected in the years of 1900 to 1904 during my activity at Loewe-Gesfürel, Berlin, which consisted in the education of a staff of inspection, and later on as head of the laboratory in Berlin-Charlottenburg.

My old friend Mr. H. F. L. Orcutt, Birmingham, who managed, in 1902, the sales-department of Ludw. Loewe-Berlin, recommended to give these figures to the inspectors and to receive *all* the machines

after these charts. Also this big firm of about 1,000 workmen already in 1902, which designed and manufactured all sorts of machines, considered carefully the question of first or second quality, but it decided tor only first quality, for the reasons given before.

It is impossible to execute machines of two kinds of precision in the same factory, without bringing the good workmen gradually down to a lower standard. The direction of to-day goes after higher precision, and it must be admitted that the Russians strongly influenced the whole world by their severe conditions when purchasing machine tools.

Later on Mr. Lang spoke of the cutting-speeds of machining for which there are to-day no limits, as every speed can be attained with the new tools. To this it must be said : This is true, but the *economic* limit only is decisive.

Too high a speed does cost much more at the purchase of bearings and lubrication, gears, axles, diameters, quality of slides, and current. The savings in time by quicker machining are lost sometimes twice or three times by an especially expensive machine and an especially strong strain ou the nerves of the workmen at the machine. The production engineer has to distinguish between highest speed and highest economy and has to care for the most economic procedure, and this is not always the quickest.

Mr. W. G. Carr : After listening to Dr. Schlesinger's paper and Mr. Lang's remarks afterwards, which carry quiet a considerable weight from machine tool producers, I still find myself in agreement with the Doctor. We production engineers have to produce to limits which, in many cases, are set down by the British Standards Association. Why cannot the machine tool makers give us our machines made to similar or some accepted standards ? Machine tools are in most cases individually built, and if the machines are individually built it seems to require very little extra effort to build them right. In fact it is easier to work right than nearly right. I do see, however, some slight offset to this fine limit gauging. That is, if the machine leaves the tool makers with a written guarantee that it is to these limits the material used in that machine should also conform to some specification. It seems to me to be foolish to make a machine to fine limits if the material is going to wear badly or distort with use. I think that, while it is necessary and advisable that such standards should be adopted, they cannot be quite acceptable until there is a standard for the material which is used in these machines..

Dr. Schlesinger : I want to answer this very important question at once : all contracts on machine-tools contain a guarantee of six to twelve months against faults in material . This general guarantee

must suffice. The designer is responsible for the whole. It is therefore useless to make still separate prescriptions for the material of gears, axles, and slides with regard to resistance, wear, etc., because then the reception would be impossible on account of the costs.

At to-day's high speeds a gear manufactured of inferior material or of bad quality, will be worn out in short time, in any case in less than one year. It must be sufficient when alignments are examined by tests and when the guaranteed output of numbers of pieces is to be attained with the required precision.

Against this one is reminded of the example of the railway. Here the material has to be examined with regard to resistance against fatigue, wear, rupture, and so on, before it is built into the engine or the wagon. But this is justified, because it is here a question of human lives, which have to be preserved and therefore the costs of inspection of material can be supported. In the case of a machine-tool it would mean an unnecessary expense.

MR. F. W. HALLIWELL (Chairman): Before we close I should like to add my tribute to Dr. Schlesinger. The London Section is proud to have had the privilege of introducing Dr. Schlesinger to the Institution. I am sure we have all enjoyed very much his lecture. Personally I find myself a little bewildered by Mr. Lang's remarks and was very pleased to hear Mr. Broomhead join issue with him. We have apparently a very curious situation in which our leading machine tool makers, while publicly acknowledging the usefulness and benefits of a limit system—and in many of their works they have themselves adopted it with every success—still turn it down and apparently leave the matter on the table. Can we as an Institution think of leaving it in this position? I think it is a subject to which we should give considerably more attention.

EX-PROVOST LANG: I do not want any misunderstanding, gentlemen. The Machine Tool Trades Association think that it would be a mistake to have one set of British limits. Do not misunderstand me. They are all in favour of having limits but there is a very large variety of tool makers from what you might say the top to the bottom, and they consider that it is in the interests of this country that each machine tool maker should produce his own limits, thus leaving it to the buyer to choose which he prefers.

In my own firm we make lathes to different limits, depending on what they are required for. If a man says he wants special limits he has to pay an extra price—whatever it may be. The machine tool makers are not averse to limits. They are in favour of limits, but they do not want to be ruled by a body of men who say you have got to use certain limits and nothing else. Do not have any misunderstanding, gentlemen, that is the position. I am not giving

you my own opinion at all now. I am telling you the point of view of the Association as a whole. I think it is my duty to do so.

MR. B. C. JENKINS: I did not know whether it was in order to raise any question relative to Mr. Lang's remarks, but really I think that each time he rises to reply he puts his foot further and further into it. We shall have a 100% case for standardisation if he keeps on. I will accept Mr. Lang's argument—

EX-PROVOST LANG: Not *my* argument, please. Over and over again—not my argument.

MR. B. C. JENKINS: Perhaps I should not have said Mr. Lang's personal argument but his argument on behalf of The Machine Tool Trades' Association. We will take it that there are machine tool manufacturers making various grades of machine tools to varying limits and for varying requirements. If this be necessary let them continue to do so but let us have standards within which those limits lie. Give us one, two, three, or four, standards if your consider it necessary, but let those standards be clearly defined so that we have a clear and quick basis of comparison.

If the production engineer who has many other jobs to do besides choosing machine tools is called upon to check and compare every individual dimension, working tolerance, limit of deflection, and so forth, which is worked to by individual manufacturers, it would simply lead to the position outlined in my previous remarks. We do not hesitate to buy John Lang's machine tools to-day because we know Lang products are made to a standard of accuracy which meets with our approval, we know they have a reputation for good accurate work and good materials. What we as production engineers want is not one or two machine tool firms working to these close standards but 20 or 30 reliable firms working within such standards.

Knowing that machines produced to such standards will produce components to the required tolerances we can specify our requirements. Failing this we must do as before and depend upon past performance and reputation. This may, of course, suit Mr. Lang better.

It appears to me that the leaders in the machine tool industry are not over-anxious to impress the necessity for these standards on other manufacturers; are they afraid they might lose out owing to more efficient competition? As regards the argument put forward by machine tool manufacturers of excessive cost of production to given standards I am not in agreement. Personally, I have spent many years in the automobile industry and have seen much more advance in it from the point of view of accuracy of production than in any other industry in the country. Increasing accuracy has gone hand in hand with reduction in production costs, admittedly volume has played a part in such cost reduction, but the production of

component parts to standardised tolerances has played a large part in decreasing production costs.

Where accuracy is essential in the final product it is much more easily and cheaply attained if you work to definite standards of measurement instead of working in a haphazard manner. If it is necessary for low grade machinery to be made to meet certain export markets let them adopt a lower standard and definitely specify that the machines are made to that standard.

A point which is often lost sight of by manufacturers is the position of the salesman offering a machine for sale to a buyer who has no close and intimate knowledge of machine tools. I, personally, am in the fortunate position of being allowed to specify and purchase machine tool requirements, but in many concerns, both large and small, they are specified by a practical engineer, but purchases are made by a buying department. The tendency of most buying departments is to buy on a price basis and imagine the position of a salesman offering a good, soundly designed and constructed machine, in competition with another which in general appearance and specification appears the same, but which, in fact, is perhaps half the price and worth less.

It would baffle the production engineer to justify the difference between say £300 and £600 for two machines which appear identical unless he could prove conclusively the difference in quality. Fixed standards of manufacture would enable a quick comparison to be made and the higher priced machine justified. In conclusion, Mr. Chairman, I would say that from whatever angle one may look, the case for some form of standardisation of machine tool accuracy such as outlined by Dr. Schlesinger is a vital necessity and calls for the closest possible co-operation between the production engineer and the manufacturer.

MR. BELLMAN : Might I put forward the point of view of a department purchasing and inspecting machine tools for export to India ? We get very extraordinary machines to inspect and very extraordinary demands to fulfil. Mr. Lang, and other gentlemen, if they could accompany our inspector on visits of inspection, would be surprised if they saw some of the machine tools. One gentleman has said that he thought if the bad manufacturers went out of business it would be a good thing. Well, it would certainly be helpful ! I should like to give an example—We had a replacement batch of 5 in. lathes under our inspection—(the lathes were not ordered by us, but through a merchant in India). We found that when the saddle was traversed along the bed, in some positions it was not possible to insert a 1/1000 in. feeler, while in others a small 4 in. rule disappeared under the saddle. Examination of the construction of this lathe shewed that the sliding jib or fitting strip (to hold the saddle down) ran along an un-machined surface with the result that

it traversed in an undulating manner. When the Inspector complained, the firm said, " Oh, that is all right, we will fit a brass jib and a piece of soft leather behind the jib to take up the slack." This was only one of the many serious defects and before the lathes were acceptable a considerable extra expense was involved. These lathes are, I have no doubt, bought largely on price and were outside our control. When we ourselves make the purchase we deal with firms of repute and we know that their limits are satisfactory. Generally, when we act as inspectors of machine tools (not purchased by us) we either prescribe our own limits, use Dr. Schlesinger's, or ask the firm what limits they propose. But some of the firms appear to have no idea what is meant by limits of accuracy, and so I do think that standard limits of accuracy are absolutely essential. The good makers would benefit because the inferior makers would have either to increase their price and work to a better standard or go out of business. As there is no British Standard set of limits the Machine Tool Trades' Association should at all events consider limits which would be agreeable to all. They might not be the minimum limits, they could be the maximum acceptable limits. If a firm worked above that, so much the better.

MR. J. PIGGOTT : I have been intensely interested in the lecture and the lucid way that Dr. Schlesinger dealt with it. It has helped further to remove any misapprehension one may have had regarding this subject. And further, as a practical demonstration, to show the possibilities, if such a standard was set up. We recently received at our works a combination turret lathe. This machine was not ordered to any specification of alignments but an " Inspection sheet " was received with it. This chart was laid aside and the machine was set down to a level in the ordinary way.

After the machine had run for a few days it was checked over by the inspector, and when we compared his measurements with the chart received from the maker's I was a little surprised to find that all the important alignments were within the limits. I would also add that they were less than the permissible error laid down by Dr. Schlesinger, although the tolerances for the machine were .0002 in. wider (that is 0.025 mm. instead of 0.02 mm.). The machine was installed on the ground floor and if it conformed to the maker's requirements it would have had a 15 in. or more concrete bed.

It would be difficult to conceive that the same results could be obtained continually if machines were laid down on the first or second floor of a building in a modern motor works with the continual traffic and periodical changing of machines, although the floor strengths may be calculated scientifically to carry given weights, deflections of a local character must occur. Would this have a tendency for precision tests to become neglected or for machines

to be developed with a better suspension or box section bed, etc., to overcome this? With reference to the multi spindle automatics, is it possible to get overlapping of the limits when spacing the spindles (permissible error 0.025 mm., .001 in.) ?

DR. SCHLESINGER: A good machine demands a strong and rigid foundation, else you cannot produce good work on it. The box-section of the bed is not sufficient—think of the heavy grinding machines—to overcome the lack of foundation. If the second floor is too weak, you must set-up your accurate machines on the ground floor.

I believe that the admissible errors, given in the test charts 18a, to 4 for multiple spindle automatics guarantee good work, but I know that the Pittler people, who are manufacturing these machines, go down to 0.02 mm. errors.

MR. ALBU: First of all, I should like to say that I found this lecture to be the most interesting one I have listened to since I have been a member of the Institution. Not only has it been one which has provoked the most discussion and apparently brought out the strongest feelings amongst members of the audience, but I think that from a general scientific and technical point of view, as well as from a practical one to us, it has been very valuable.

I was very interested to hear that the origin of the adoption of these limits came from the necessity of standardising tests on high class machines for the trade between Germany and the Union of Socialist Soviet Republics. This, I think, must have been a very surprising piece of information to many of our members. We all knew about the very large number of modern machine tools being bought by Russia, but it is very interesting news to hear of the very high class of accuracy they demand. I should imagine that one of the reasons, apart of course from the effects of centralization of purchasing, that they demand such standards is, as Mr. Jenkins pointed out, that of rationalization. These standards of limits in a country like Russia where there has been a great lack of skilled labour and technical knowledge must save a great deal of time in the specification, purchase and inspection of machines. And what applied in Russia must surely apply elsewhere. I think with the very greatly extending use of precision machine tools the same argument would apply in other countries, including this country. I should think it would help to save a lot of time. In the small shop there is not a separate staff for specifying and testing machine tools, nor generally is there very much time for this work. In most cases machines are bought some months after they are really required. Fixed standards of limits and testing would be very valuable in these cases.

With regard to the objections put up against Dr. Schlesinger's limits, the first is that there is only one class of limit. Of course,

if there is only one class of limit machines can either be bought to the limit or to no limit at all. This does not preclude the buying of second class machines.

With regard to Mr. Lang's remarks about loss of export trade, I should be inclined to put the argument the other way round. He said that members of the machine tool industry were frightened of losing trade in cheap tools, but I should think that probably one of the biggest reasons for our loss of export trade was that we had not sufficient manufacturers able to supply machines to the very high standards of accuracy now required and were not able to issue a standardised system of tests and limits. I do not know how far this is true, but our trade with Russia, for instance, has never been so high as that of Germany and U.S.A.

Perhaps the most interesting part of the lecture was the diagrams, in particular those showing the deflections and stresses in various directions of machine tools. These, I think, will make us look upon the tool tests in quite a different light, because they show that what may appear at first sight to be a question of the fixing and making of limits are not just things to be done in the office, but something that depends on the working conditions of the machine.

Finally, Dr. Schlesinger apologised for his English, but I think it has been amazing—the clearness with which he gave his lecture and the graphic way in which he held our attention and kept us interested from beginning to end. I ask you to respond to the vote of thanks given to Dr. Schlesinger in the usual way.

SCREW THREADS—THEIR TOLERANCES AND APPLICATIONS

Paper presented to the Institution, Preston Section, by W. Wilcock, M.I.P.E.

Introduction.

IN this short paper on screw thread production, gauging methods and tolerances, it is intended to give the latest practice in the modern automobile factory, under every-day practical conditions. Until a few years ago, the production of the threaded hole had received but small attention, in comparison with the production of the screw or bolt, and at the same time, threaded holes were produced with the black tap. This tap could be machined to reasonably close limits, but the main trouble was encountered as soon as the tap was hardened or heat treated, when errors to pitch and thread were evident, due to distortion, and at that time, no method of correcting these errors was available. Similar errors were also met with in the round type screwing die which was produced in a similar manner to the black tap.

The Modern Ground Thread Tap.

To-day, however, we have the ground thread tap, the size and shape of which is controlled after hardening, so that heat-treatment distortion is completely eliminated, and very fine accuracy is maintained in size, thread form, pitch, cutting angles and relief, and the tap manufacturer is now in a position to offer the user, ground thread hand taps to limits indicated. Take for example the $\frac{1}{2}$ in. Whitworth 12 T.P.I. hand tap, the standard tap has an effective diameter oversize of plus .0020 to plus .0015 over nominal size, and that the "A" tolerance tap has an oversize on effective diameter of plus .0005, plus .0002.

These sizes are guaranteed by the manufacturer to .0003 in., and the guaranteed limit on the pitch is .0002 in. per inch of length, and the flank angle is also to $\pm$ 0°-30′ per half the included angle. These limits are very fine and show the wonderful strides made in this direction during the past few years.

The Modern Die Head with Ground Thread Chasers.

Great progress has also been made since the days of the solid type die, and following the introduction of original type of die

head, we now have the up-to-date self-opening die head, with inserted dies, which are ground and lapped to such accuracy as is equal to the production limits for taps. The die head itself is also a perfect example of machining, hardened and ground all over, so that misalignment of the dies is negligible, and so we have a tool capable of dealing with the ever increasing demand for rapid production at high cutting speeds coupled with the highest quality of threads.

Gauges.

In the measurement of screw threads, all the elements must be taken care of, so as to ensure interchangeability. The important feature of a screw are as follows : Pitch, effective diameter, thread form, major diameter, and core diameter. These latter two are not as vitally important as the other elements, but must be controlled so that no interference results.

In the case of the threaded shaft, we have standardised the use of the roller type of screw gauge for shop use, and the Wickman type screw gap gauge for inspection use.

On the Wickman type gauge the " go " anvils, that is the front anvils, are of full form, ground and lapped to correct pitch and thread form, and the anvils are set to the effective diameter desired with the aid of a hardened master setting plug. The rear anvils are of truncated form, being so designed as to gauge only on the effective diameter, and are also set to size with a hardened master plug, these are the " not go " anvils. There has been some criticism levelled at the roller type of gauge, but we have found it satisfactory if set to the same master plug gauge as the Wickman and used by operator, who is checked by the inspector with the Wickman. The roller type is not so liable to damage by the operator during constant use (trouble of the faces snipping off with the Wickman).

The gauging of the tapped hole is done by means of hardened screw plug gauges the " go end " of which is of " full form " guaranteed to extremely fine limits for size, pitch, and thread form, and the " not go " plug is of truncated form to check the effective diameter only.

Tolerances.

I think you will agree, from my earlier remarks when I say that the tap manufacturer and the die head manufacturer, are both able to supply the user, screwing tools which are extremely accurate to very fine limits. With this thought in our minds let us consider the fundamental principles which influence any system of limits or tolerances on screw threads.

The main features of the screw thread are the pitch, effective diameter and thread form, and as the effective diameter is the im-

portant measuring size, any tolerance set must accommodate any errors in pitch and thread form, as well as working limits for production purposes.

We have taken the threaded hole as the basis from which our conclusions are drawn, and I think this will be accepted generally by engineers, when viewed from this angle. Firstly we have standardised the S.K.F. hand tap, on all machine tapping in the factory, using of course suitable holders and adaptors of a non-floating type. This tap is a standard product of competitive price but manufactured to close limits and with extreme accuracy, guaranteed as previously mentioned earlier in the paper. This you will see enables us to control the size of the threaded hole, and it is clearly advisable that there should be only two classes of threaded hole, as produced by the standard tap, and the "A" tolerance tap, because any increase in this direction obviously leads to a more complicated system of tolerances and generally speaking, elaboration, and complication, lend themselves to inefficiency in production.

At this stage, let us look at a chart showing the Herbert and B.E.S.A. tolerances and examine the ½ in. Whitworth 12 T.P.I. as a typical example and we see that the following conditions *can* arise.

Herbert Tolerances	Nuts	Bolts
M.	Plus .0005 to plus .0080	Nominal to —0075
F.	Plus .0005 to plus .0065	Nominal to —0060
S.	Plus .0005 to plus .0050	Nominal to —0045

B.E.S.A.	Nuts	Bolts
Standard fit	Plus .002 to plus .0078	Nominal to —0058
Close fit	Plus .002 to plus .0049	Nominal to —0029

It can readily be seen that it is possible to have a state of affairs when the difference between the nut and the bolt using the Herbert "S" tolerance, is .0095 and in the case of the "F" tolerance .0125 in. and the "M" tolerance .0155. The "M" tolerance is the recommended range as suitable for high grade interchangeable work as required on automobiles and machine tools, and the "F" tolerance *only* on the highest grade of work as on aircraft and instrumental work. Now, gentlemen, this is where I differ in question of

tolerances. In the first place, it has been proved in practice that, using the modern ground thread tap with its super-finish, the threaded hole size can be controlled from nominal effective diameter to plus .0025 without difficulty.

Secondly, bolts and screws are comfortably held to Herbert's tolerances in every day practice using the modern die-head, and so it is maintained that an oversize tolerance of .0005 over and above the maximum size of the standard ground thread tap is a reasonable maximum tolerance for threaded holes with basic size as minimum.

From actual practice it has also been determined that the Herbert "F" tolerance is ample for bolts and screws as are used on our class of work in automobile engineering, and as the resulting fit between them is a first-class job, I do not hesitate to say that the Herbert recommendations of "M" tolerances on both the threaded hole and the threaded shaft are too large, as we have been working to much closer tolerances for some considerable time.

These are the tolerances we have used successfully over the period of three years. During this time, our experience has shown that there is a definite desire on the part of the operator to consistently work to the "go" end of his gauge, or should I say he will persistently try to obtain a light feel with the "go" pegs of his gauge.

I believe that there is a definite psychological effect created by the fact of the operator, desirous on the one hand to avoid making scrap work, on the other hand, from the probable hint or suggestion from the inspector that he ought to complete or try to complete the component as full as possible to the " go " pegs of the gauge.

I do not think that it is generally possible to expect an operator to work to a reasonable degree of accuracy for a maximum part of his time, that is to say to work 90% of his time producing to B.E.S.A. close tolerance or Herbert "S" tolerance, and then to call upon him to produce for the next 10% of his time tolerances in the neighbourhood of "M" or "R". I think you will agree with me that there is something in my remarks with reference to the psychological effect upon operators in asking for accurate work and then making a request for a coarse class of work.

This is hardly a reasonable request to make to the average operator. If we take a look at the slide (*shown on screen*) you will note the chain line immediately below the nominal or basic diameter line. This I feel, will give, or assure the designer that he will be able to obtain a screw particularly to the coarser limit which has a definite minus nominal diameter as you will notice from the slide. This minus diameter, to the "go" end of the gauge, is only used when we leave the B.E.S.A. close tolerance and Herbert "S" tolerance, that is to say the "F" and "M" tolerance (and I might

state at this juncture that the "M" tolerance is not used in our class of work).

One of the chief reasons for the fixing of a minus nominal basic "go" diameter will be seen on the examination of the limit system as fixed by Messrs. Newall. You will know that the tolerance fixed for a plain hole, having "go" and "not go" plug gauge, that the "go" end of the gauge begins with a definite minus nominal size. Where you have a class of operator similar to the one I have already described, it is quite possible to give him a gauge set to the Herbert "S" tolerance, and also a gauge set to the Herbert "M" tolerance, and from the fact that the "go" anvils are set to exactly the same size you can reasonably expect to obtain the same size of screw from either of these two gauges, that is to say the "no go" gauge or the full extent of the tolerance is very rarely indeed absorbed. By adopting this minus nominal basic line we expect to find that the system is nearer fool proof or shall I say less dependent on the human element to obtain the difference in the class of fits.

In support of my statement I would call your attention to the results of measuring a screw $\frac{1}{2}$ in. Whitworth 12 T.P.I. picked at random from the tray of an old Foster Capstan equipped with a standard $\frac{3}{4}$ in. type "C" style "H" Herbert die head having suitable dies for cutting steel. The form is very good as far as can be judged. However, we took a more thorough examination, and the following figures are the results :—

EFFECTIVE DIAMETER.

FRONT—.0043 in. MIDDLE—.0038 in. BACK—.0031 in.

MAJOR DIAMETER= —.0005 in.

PITCH=ERROR of Plus .0012 in. on 12 threads.

THREAD FORM = Three separate threads were tested for flank angle error, variations given on half angle of 27 —30.

No. 1 Thread = —0°—0ft.—27 in.
No. 2 Thread = —0°—4 ft.—46 in.
No. 3 Thread = —0°—18 ft.—30 in.

I think you will agree that this is a first-class commercial job.

It is probably in the minds of more than a few of my audience here tonight, that I have not gone into any detail in regard to the effect of pitch error and flank error on the effective diameter so we will just look briefly into these points, which unquestionably warrant investigation

The quality of a thread is determined by its load capacity or its mechanical strength, and this is in turn controlled by its effective diameter which is the diameter at a point half way up the flank of the thread. This is the point at which the thread has to bend or shear before the thread gives way, and must therefore be controlled accurately to obtain the maximum efficiency.

It should be clearly understood that there are two kinds of effective diameter, the *simple* effective diameter and the *compound* effective diameter. The former is the diameter as measured by needles or wires, which is an individual thread size, but the latter is the diameter as measured over a series of threads at one setting, this incorporating any possible errors in pitch, flank angle or major diameter.

It will therefore be appreciated, that a screw which has passed through the "go" end of a Wickman type of gauge must of necessity enter a tapped hole whose compound effective diameter is identical to the size and accuracy of the gauge. Half the pitch error, or "X" requires a compensating amount "2X" in vertical direction, and as this also takes place on the opposite side of the diameter, we see that "4X" is required on the diameter, this is equal to twice the pitch error on the effective Diameter.

The maximum permissible flank angle error on modern taps and dies is ± 0°—30ft. which is equal to 1°—0ft. on the full angle of 55° for a Whitworth thread, and this of course requires to be compensated on the effective diameter and using the B.E.S.A. formula for this, we find it works out to be .001.

Suppose we now apply the necessary rectifications to the ½ in. Whitworth screw I have mentioned earlier in the evening. The pitch error in that case was, you remember, .0012 on 12 threads, on 1 in. length of engagement, and therefore the compensation on effective diameter on this length of engagement (which is twice the length of a standard nut) will be .0024, and although the flank angle error is well within the allowable ± 0°—30 ft., suppose we take the .001 compensation as required. We then have a total of .0024 plus .001 = .0034 in. required on the effective diameter to compensate for pitch, and flank angle, errors, and in the Leyland tolerance of plus .002 for the tapped hole, and the Herbert "F" tolerance of .006. For bolts and screws the maximum condition is .008, and the average condition is about .006, you will see that the compensating allowance for pitch error and flank angle errors are well catered for, and consequently it is not necessary to be unduly worried about these errors using present day high precision tools, as it is almost impossible for them to attain the proportions of a few years ago.

Studs.

The tolerances to give interference fits necessary for stud fits are subject to varying conditions such as (1) the material to be screwed into; (2) whether screwed into a small boss or solid block; (3) whether screwed into a thick or thin flange; (4) whether a normal stud fit or an extra tight stud fit is required.

In the early period of experimenting with stud fits, many of the studs were heat treated, and some considerable time was spent in checking the amount of " shrinkage " that took place in a range of sizes of studs after heat treatment in the old type coke furnace, as this " skrinkage " was an important factor in the setting of suitable interference sizes. This " shrinkage " was due to oxidation or scaling, but since the introduction of modern oil furnaces, the oxidation can be cut down to a minimum by keeping the interior of the furance in a " hazy " condition by suitable manipulation of the nozzles. In fact we do neglect this small alteration of size in studs of a " standard " nature. Still further experiements gave us data from which an average of .001 above the maximum tap size was found to be a suitable interference size for all studs of a general character. Should an extra tight fit be required the standard tap is replaced by an " A " tolerance tap which is, you will recall, close to basic effective diameter, and we can therefore obtain that extra tight condition desired. (There are, of course, conditions met with that are out of the ordinary and special attention has to be paid to them, but these are known as special stud fits).

Conclusion.

It is fully realized that the subject of screw threads is too comprehensive a matter to obtain the attention due in a brief paper of this description, as there are so many types of threads to be dealt with, as well as the non-standard type which come under the heading of " special " and, as such, demand individual attention when the fixing of tolerances is undertaken. It is definitely felt, however, that there is room for further investigation into this very interesting subject by the people responsible for fixing screw thread tolerances, and it is hoped that this short paper will have the effect of stimulating interest and comment amongst them, to the advantage of the general user and producer of screw threads.

I should also like to say that I have brought along with me to-night a few samples of screw threads which perhaps point out more forcibly than words, the effect of various classes of tolerances between screws and threaded holes, and they will be open for inspection when the lecture is over. Might I mention before concluding, that I am indebted to Messrs. Herberts and Messrs. A. C. Wickman and and Messrs. Newalls for their co-operation and loan of some of the slides shown this evening.

List of Slides Shown during the Lecture.

Slide No. 1—Ground thread tap tolerance ... Leyland No. 387
No. 2—Illustration of Coventry S/C die head ... ... Herberts
No. 3—Supporting of the die ... ... Herberts No. 3

No. 4—Cutting angles of Coventry dies	Herberts No. 4
No. 5—Illustrations of Wickman gauge	Herberts No. 38
No. 5A—Illustrations of Newall roller gauge	Newall
No. 6—Action of anvils	Herberts No. 40
No. 7—Testing thread on M/C	Herberts No. 45
No. 8—Setting plugs in anvils	A.C.W. No. 8
No. 9—Setting plugs being used ...	A.C.W. No. 9
No. 10—" Not go " plug for tapped holes	Herbert No. 44
No. 10A—" Go " and " not go " plug for tapped holes	Newall
No. 11—Thread elements	A.C.W. No. 11
No. 12—Herbert S-F-M Tol. and B.E.S.A. Tol. chart	Leyland No. 384
No. 13—Leyland Tol. chart	Leyland No. 385
No. 14—Shadowgraph of screw form ½ in., 12 T.P.I.	Leyland No. 386
No. 15—Effect of pitch error	A.C.W. No. 15
No. 16—Screw in position showing pitch error	A.C.W. No. 16

UNVEILING OF THE HUTCHINSON MEMORIAL PORTRAIT.

THE unveiling of the Memorial Portrait to the late Mr. R. H. Hutchinson took place at the headquarters of the Institution, British Industries House, London, on the afternoon of March 14, 1936.

Lord Sempill, President of the Institution, was in the chair, and Mr. J. A. Hannay, Past-Chairman of Council, unveiled the portrait. The attendance included the following members of Council, in addition to the President and Mr. Hannay : Mr. T. Fraser, Chairman of Council ; Mr. J. D. Scaife, Past-President ; Messrs. R. W. Bedford, J. W. Berry, J. H. Bingham, S. Carlton Smith, H. A. Drane, E. P. Edwards, W. Groocock, A. T. S. Groombridge, G. H. Hales, F. W. Halliwell, E. W. Hancock, S. M. Hardaker, H. A. Hartley, E. J. H. Jones, H. G. King, W. M. Rudge, T. White, F. Williams, and J. G. Young. A numerous attendance of other members of the Institution included Mr. A. J. Aiers, Past-President, Coventry Section ; Mr. W. G. Carr, Chairman, London Graduate Section ; Messrs. F. A. Oakley, R. Zieschang, etc.

Mrs. Hutchinson and her two sons, together with other relatives, occupied places of honour at the ceremony.

LORD SEMPILL, President, said : As President of the Institution I am proud to be in the chair at this ceremony designed to do honour to one who held with so much distinction the office I now hold. It is only a year this month since Mr. Hutchinson died, and it is evidence of the esteem in which he was held that within twelve short months of his death we should be here to unveil a memorial to him.

I regret that I had not the advantage of knowing him personally, but I have heard with admiration of his work for the Institution. I am told that he was a man of marked ability and of singularly forceful personality, whose outstanding contribution to the welfare of our Institution was that he helped in no small degree to pilot it through its early and difficult years.

There are those here to-day who also bore a leading part in that pioneer work, without whose labours and co-operation success could not have been achieved, but the grim hand of death has decreed that it is Mr. Hutchinson who is to be the symbol, through this memorial, for the work which he and they accomplished together. More fortunate than he, they are still here to help in building further on the foundations already laid.

This is not an occasion on which you will expect many words from me, as the unveiling of the memorial portrait is to be carried out

by Mr. Hannay, who was a fellow-worker with Mr. Hutchinson not only in the Institution but in the same business firm for some years as well. Mr. Hannay succeeded him in the office of Chairman of Council, and as Chairman of the Memorial Committee it is proper that he should perform to-day's ceremony. Let me say how much we appreciate the presence here amongst us to-day of Mrs. Hutchinson and her sons and other relatives. It must be some consolation to them all to know that recognition is being given to the work Mr. Hutchinson did for the Institution, and that his memory will be perpetuated by the portrait to be unveiled to-day and by the Hutchinson Memorial Medal which is to be given every year for the best paper by a graduate.

And now before calling on Mr. Hannay, I would like to pay a tribute to the painter of the portrait, Mr. William Carroll. He has had a difficult task painting a posthumous picture and I think you will agree when you see his work that he has done it very well indeed. I now call on Mr. Hannay.

MR. J. A. HANNAY said: My Lord, Ladies, and Gentlemen, before unveiling this picture I would like to say a word or two. I knew Mr. Hutchinson for nearly twenty years. Possibly many of you knew him as long or longer. Eight years ago I knew him very intimately, and for the last seven years I worked with him in the closest association. In the few remarks I make I want those present who have also worked for the Institution not to think that in any way I depreciate any work that they have done. I am thinking to-day of Robert Haller Hutchinson and the work he did. We shall all have our turn.

Robert Haller Hutchinson was our 151st member. When he died there were 1,200 members. When he joined the Institution the income was £213 per annum. Last year it was £2,138. He was elected Member of the Council in 1924, on which he served until his death last year. If you were to look back a year or two it would hardly have been possible to have imagined a council meeting without Mr. Hutchinson present. He was President of the Institution from 1925 to 1927, Chairman of the Council during 1927 and 1928, Chairman of the Development Committee from 1924 to 1935, and Chairman of the Institution Advisory Committee to the City and Guilds of London Institute on Machinists', Fitters', and Turners' Work. During his membership he saw twelve new sections added to the Institution, at which he actually attended and spoke at six of the opening meetings, including Birmingham, Manchester, London, Luton, Eastern Counties, and others; and I know he paid a special visit to Glasgow. Coventry knew him well. He was also our senior Trustee.

The Institution, which started in 1921, included some very able men, but a year or two afterwards it seemed to fade somewhat.

Then Mr. Hutchinson joined. He helped so much that very soon he was made President. He had a vision of the possibilities of the Institution and in his vigorous way suggested that we ought to go out into the highways and byways in all parts of the country and see what could be done. From the time that he helped to start the Birmingham Section our Institution has gone on by leaps and bounds. I believe that if it had not been for Hutchinson at that time the Institution would not have made such rapid progress. I question whether there was any one else among us who possessed the vision to see the possibilities he saw, and he was fearless. Many times—many times—I thought he was going far too fast. I remember in Manchester when the Manchester Section was being formed, being alone with him in the hotel after the meeting there, and getting to know something of the real Hutchinson. He had been so proud and so pushing, so vigorous at all our meetings, but there in the hotel he confessed to me that the encouragement that he had got in the provinces—in the sections that he had formed—more than repaid him for everything that he had done. I shall never forget that night in Manchester—his gratitude and pleasure for the support he received.

What I would like to see is this. As he has passed away others have got to step into the breach. Conditions in the world now demand certain things. This Institution has been called into being to assist, and I do not see how we can do anything else bnt go on and on.

At the last meeting but one that our Past-President, Sir Walter Kent, attended, it was suggested that we should have a memorial to our late member, and we did hope that Sir Walter would have been here to hold this position I am occupying to-day. I have not seen anything so unanimous, I have never seen anything that came so naturally and easily, as the way that this memorial has been arranged. We have about 15 or 16 sections now, and the subscriptions and help have come from severy section, from every part day after day, and a couple of months after it was first announced the whole fund was closed and the money required obtained.

I said a moment or two ago that we could hardly imagine a Council Meeting without Hutchinson, and I am proud to think that from now on at our meetings at Headquarters, when we are considering the tasks in front of us, we will be able to look on the wall and Hutchinson will still be with us. And as young people and others join us in years to come and look up and see the picture, they will ask : " Who was that ? " And they will be told, " That was a man who in its early days did great work for the Institution."

Mr. Hannay then unveiled the portrait, which is regarded by all who knew Mr. Hutchinson as a faithful and characteristic likeness

Owing to illness the painter of the portrait, Mr. William Carroll, was unable to be present. The picture bears the following inscription: "ROBERT HALLER HUTCHINSON (1884-1935), President, 1925-1927. Presented by Members as a Memorial of his Work for the Institution. (William Carroll, pinxit)."

After the unveiling tea was served, and in the evening a company of between 30 and 40 (composed of members of Council present at the ceremony, and their ladies), were the guests of the President Lord Sempill, at a theatre party.